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DIME-SIZED JET ENGINES

REFORMING DRUG DISCOVERY

HOW TECH FAILED HIM

NETWORKING TECHNOLOGIES WERE MEANT TO TRANSFORM THE U.S. MILITARY. THEY DIDN'T WORK IN IRAQ.

LT. COL. ERNEST "ROCK" MARCONE, WHO COMMANDED A BATTALION IN IRAQ

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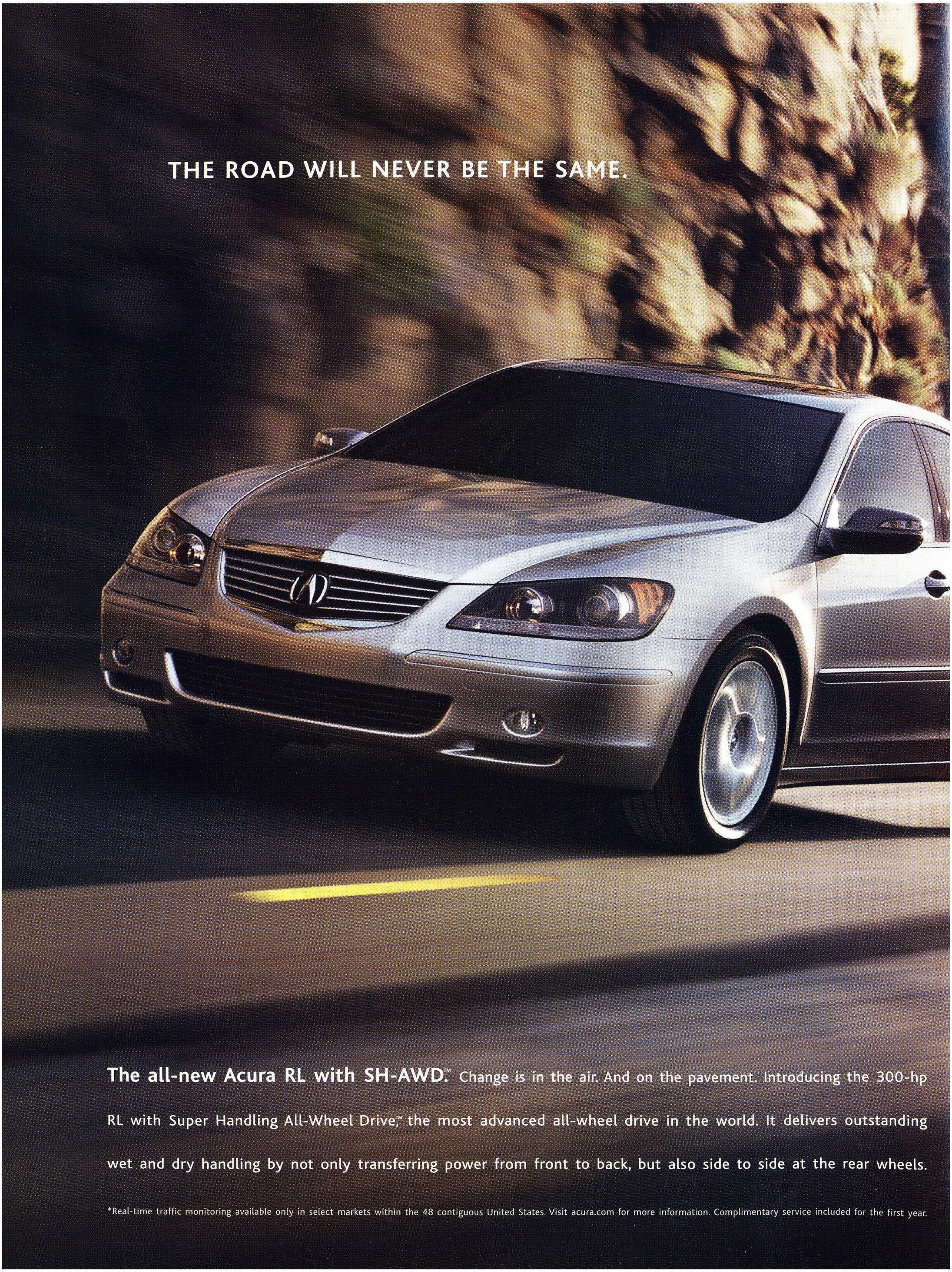
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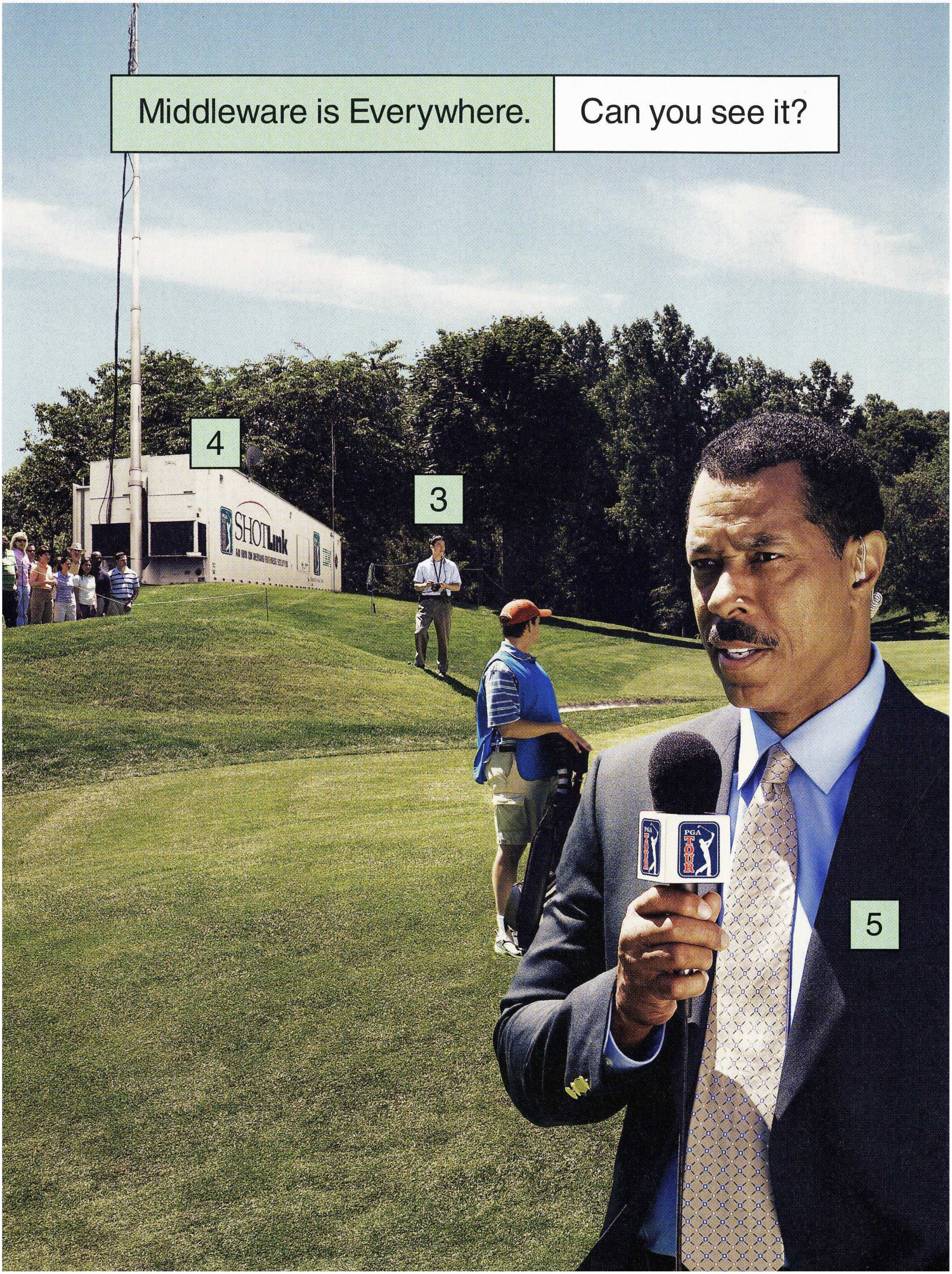
Middleware is Everywhere.
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Cover photograph by Bryce Duffy

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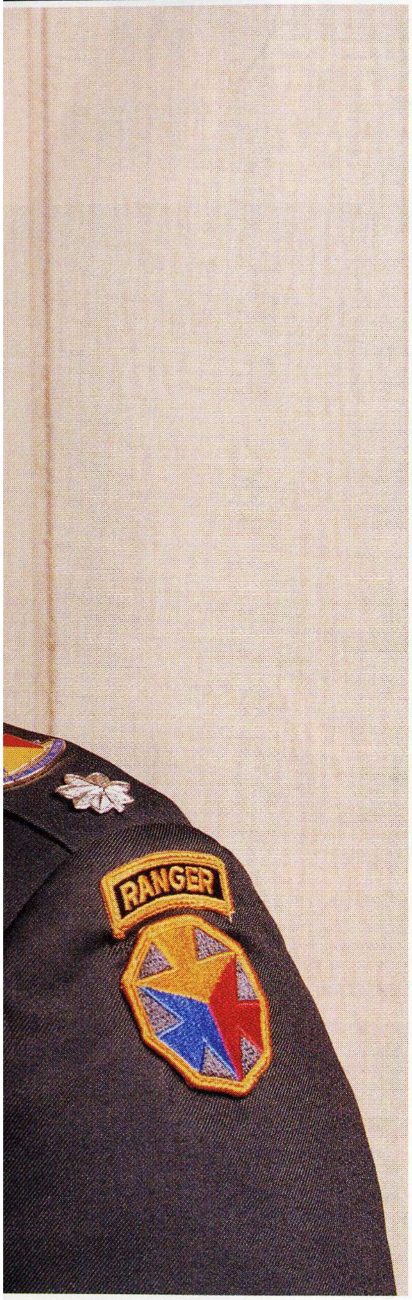
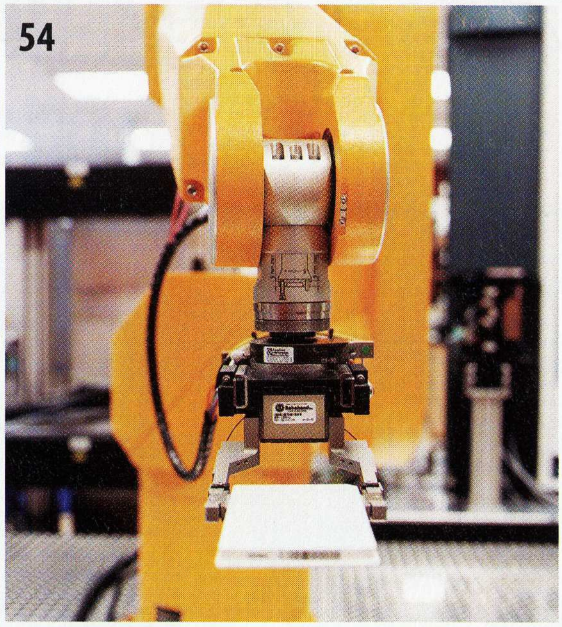
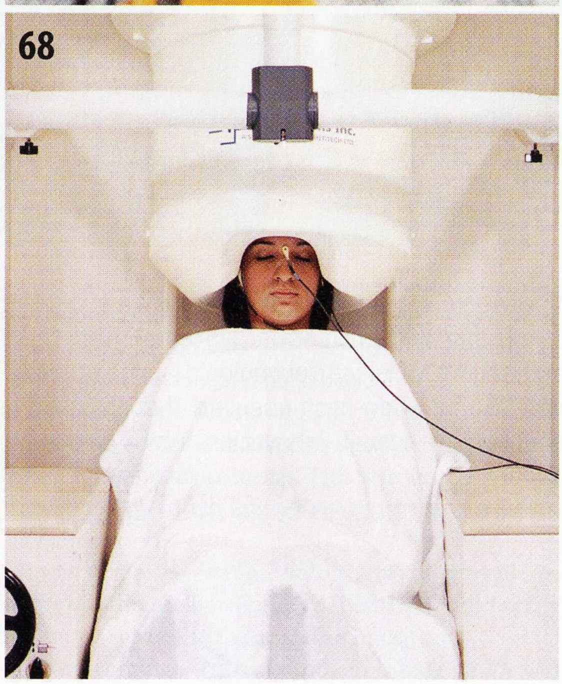
Technology Review
Volume 107, Number 9
November 2004

"A lot of the guys said, 'Enough of this s—t,' and turned it off." —*Walter Perry, p. 40*







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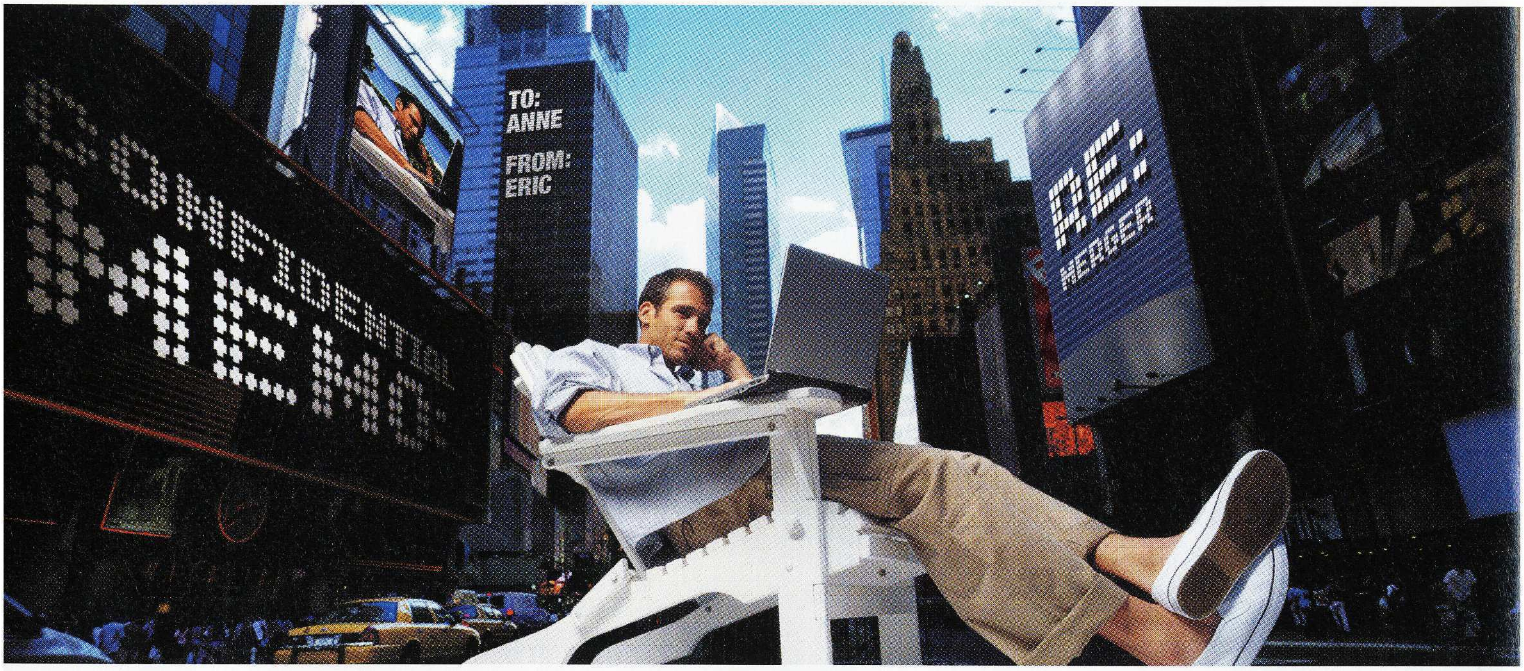
30,000,000 PEOPLE SHARE INFORMATION WIRELESSLY. THE QUESTION IS, WITH WHOM?



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Technology and Democracy

CONSIDER THIS PICTURE of civil discord. The U.S. elections this November are close. Once again, victory turns on the electoral votes of disputed states like Florida. But officials in the disputed states have purchased a new voting technology that has returned dubious results in previous elections. When all the votes have been counted, they are divided within the margin of statistical error. Election laws mandate recounts. But the new technology has no mechanism for a manual recount. To many Americans, the election seems illegitimate. Technology is blamed.

This year, around 50 million voters will cast their votes using electronic machines. Electronic voting was implemented with the best of intentions. After the Florida recount of 2000, Congress was determined to wean American voters from punch-card voting. The Help America Vote Act (HAVA), passed in October 2002, provided $3.9 billion in federal funds to help states upgrade their election technology. States rushed to buy new devices, including touch-screen machines. And HAVA was, by its own limited lights, a success: the proportion of voters using punch-card machines will be only 14 percent this year, compared to 31 percent in the last election.

So what's wrong? A lot, actually. Earlier U.S. elections that featured electronic voting do not inspire much confidence. To take just one example: in an election in Indiana in 2003, 5,352 voters produced 144,000 votes. Successive independent studies have found security breaches in the software of the most commonly used machines.

The subject inflames political passions. The most paranoid critics of electronic voting believe that the machines have actually disenfranchised voters: in the August 16 issue of the left-leaning magazine the *Nation*, Ronnie Dugger wrote that Senator Max Cleland's loss in the 2002 Georgia election (in which electronic voting machines were widely used) was "highly suspicious." Dugger insinuated that the electronic machines, some of which had been stolen before the election, had been hacked.

While the fears of the conspiracy-minded are almost certainly misplaced, election officials in California and Ohio were so worried about accuracy and security that they simply halted the rollout of the machines in many counties. This was wise, but it will be a pity if electronic voting is discredited. E-voting in itself makes sense: it is faster, more accurate, and easier than any alternative.

How to fix what's wrong? One way to make electronic voting *seem* safer would be to build machines that print receipts of individual ballots. A paper trail would verify a contested election and would do much to soothe the anxieties of critics.

But a paper trail wouldn't solve everything. The real problem is how HAVA was implemented. Because of our American preference for free-market solutions, our respect for intellectual property, and our impatience with outmoded technologies, we encouraged multiple private companies to hurriedly develop proprietary systems whose software they owned and administered. The results were predictably messy; and the companies, protecting their investments, were predictably secretive.

By contrast, in other countries electronic voting is a public utility, where the machines are owned and maintained by the state. Not coincidentally, electronic voting has been used without incident in countries as various as Australia, Brazil, and India.

At issue is whether Americans should trust digital technologies, or at least *these* digital technologies, to record our votes. The answer is, not yet, or not with these particular machines, implemented as they were in haste and disorder. Alas, it is far too late to make any changes. Americans must hope for an unambiguous electoral result. **Jason Pontin**

NEXT ISSUE

Nuclear Solution
Mounting mounds of nuclear waste are not only an environmental nightmare; they are a national-security disaster waiting to happen. And years after it was slated to open, the supposed solution—the Yucca Mountain nuclear-waste repository in Nevada—remains mired in legal and technical problems. Temporary above-ground storage is emerging as the de facto solution—but what at first might seem a dangerous short-term fix makes far more sense than you think.

Verizon's Gamble
Phone giant Verizon has been losing residential customers for years. But it is no longer content to sit back while cell phones, free Internet calls, and other companies reinvent the phone business. It's spending billions to run fiber-optic lines to customers' homes and replace its old switching hardware with technology that treats telephone calls like Internet messages. It's a huge gamble that could transform the phone network.

Biogenerics
A new generation of powerful and effective biological drugs has saved countless lives. But these drugs, the product of a booming biotech industry, are also expensive, some of them costing hundreds of thousands of dollars over the course of a year. Generic versions could supply a cheap and safe alternative, but they don't yet exist. Why not?

Special Report: R&D Scorecard
Technology Review's annual ranking of the 150 largest corporate R&D groups reveals who is spending what on tomorrow's technology. With a series of profiles of industry's most promising projects, this special report provides a snapshot of the future of innovation and helps to identify who will be its key players.

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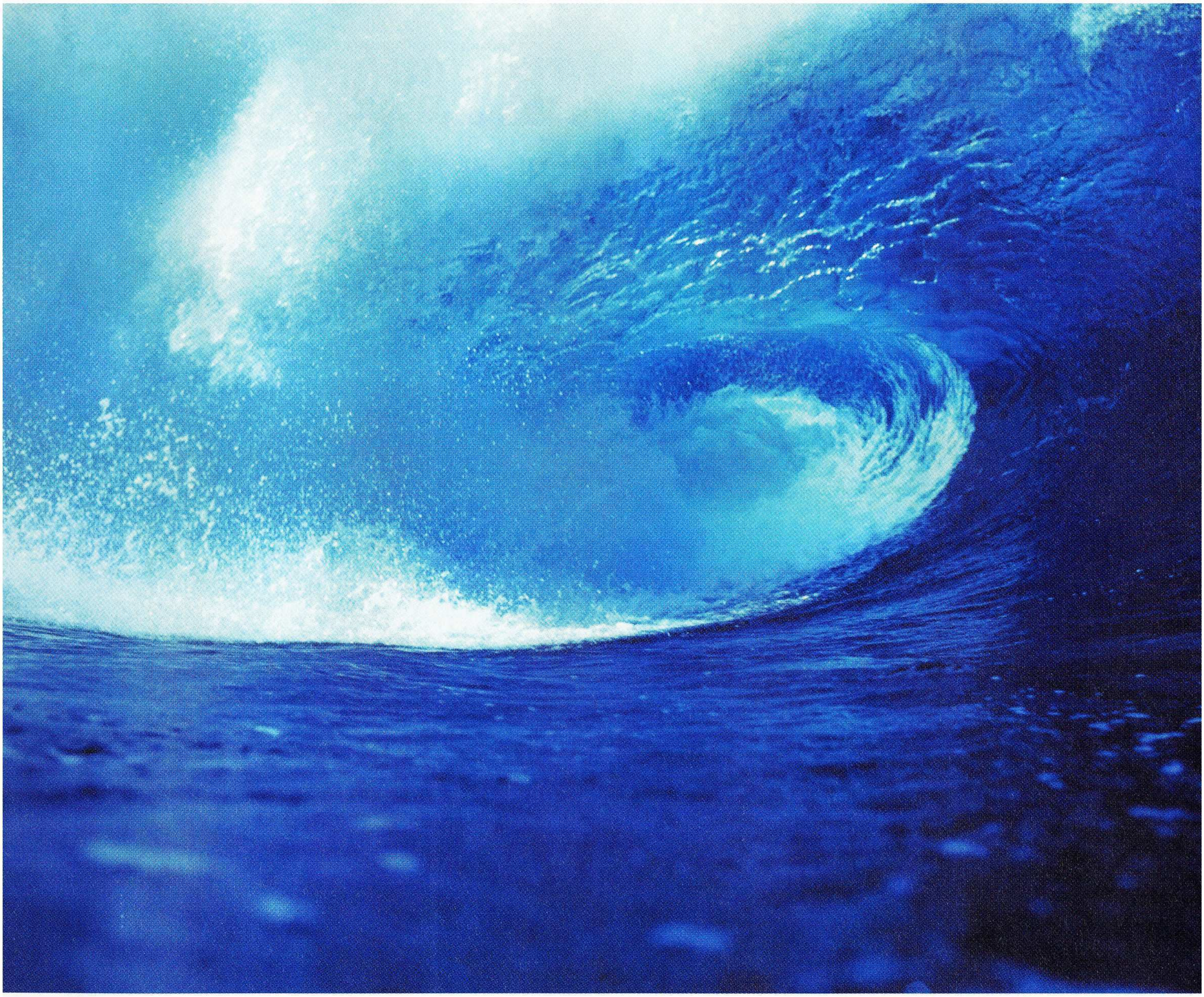

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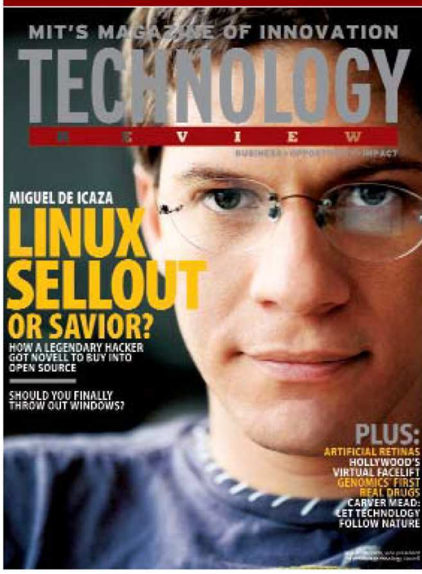

"Linux is practically guaranteed to be successful in today's market."

WINDOWS VS. LINUX

I COULDN'T AGREE MORE WITH WADE Roush's article ("An Alternative to Windows," *TR* September 2004). Linux is practically guaranteed to be successful in today's market. Not only is it cheaper than Windows, but it uses fewer resources and is less prone to viruses. Now that its graphical interface is similar to Windows XP's, its sales have been soaring with corporations and government agencies worldwide. Microsoft claims that retraining IT to support Linux would cost more than staying with Windows, but this is only a partial truth. Perhaps one of the best qualities of Linux is that it's all open source—free to everyone. It's about time Microsoft shared the market.

Siobhan Kivler
Canaan, NH

I APPLAUD THE PEOPLE SUPPORTING open-source software. But change must come more quickly. Linux has been around for 13 years. Have the strides really been so striking? Or does our desire to see open source succeed drive us to acknowledge Don Quixote's modest success? Implying that Microsoft provides banal software is simply untrue—particularly when we concede that Linux is a good choice for customers who are willing to give up bells and whistles for a low-cost opportunity. Criticism of Microsoft is a popular sport that ignores the excellent application software available for Windows XP. Microsoft's success and ethics provide a playground for legitimate critics, as well as criminal hackers and virus authors. If Linux were to become the target in this sport, would it survive the same level of scrutiny and attack? Will Novell's business model work? Or will Microsoft become the leading open-source vendor? I'm rooting for the Novells of the world.

James T. Cassidy
Kansas City, MO

AFTER TRYING TO USE THE LINSPIRE operating system since its first version, and still trying with version 4.5, I have about given up. The biggest problem with this Linux system from Lindows (or Linspire) is a lack of support for all but a few pieces of hardware. If you have to buy a computer with the software installed and can only use certain upgrades to your hardware, you might as well go really wild and go get an Apple system.

Eric P. Freischlag
Lyndonville, NY

A STANDARD LINUX DESKTOP?

NONTECHNICAL READERS OF THE ARTICLE on Miguel de Icaza ("Sellout or Savior?" *TR* September 2004) could come away with the idea that Gnome was the first graphical-user-interface option for Linux or Unix systems. In fact, there are several other contenders, some of which were operational before Gnome was even thought of. The upside of this is that you have a choice. The downside is that it's hard to produce a completely standard Linux desktop that everyone can get behind. I'm confident this will sort itself out in time, but at the moment, for those of us who want to promote and support free (as in speech) software, it's one more thing you just have to deal with.

Patrick J. O'Callaghan
Caracas, Venezuela

AS A FREELANCER WHO HAPPILY USED Lotus, I was angry when I discovered that I had to use Microsoft products to be compatible with my colleagues; they were unable to successfully open my files, whereas I could access theirs. That compatibility should run both ways to allow freedom of choice. This should be the premier principle in all software development. It is an issue that should not have been allowed to be so overridden by one company to the detriment of so many others. I agree with the path taken by de Icaza and Novell, as it requires the conjunction of rebelliousness and maturity to create solutions to innovate. Changes in our attitude toward intellectual property, and the dawning realization that by sharing we gain greater rewards, make this a timely merger, and I wish them success.

Ann Marie Shillito
Edinburgh, Scotland

FUELING ACID

THE SOLUTION OF USING FORMIC ACID AS a fuel source ("Ant Power Packs," *TR* September 2004) may lend itself more to applications other than cell phones—because of the caustic nature of the acid, and the problems associated with improper use and accidental ruptures. Refilling the fuel cell by hand is impractical for formic acid or even methanol. A possible solution would be to use a docking station to refill the fuel cell, thus eliminating any contact with the fuel. Any type of fuel cell should first be proven in devices much less robust than the common, everyday cell phone. That way consumers can build confidence in this new alternative power source.

Brian Glassman
Orlando, FL

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How to Care for Your Big, Wonderful
High-Performance Brain

The high-performance cerebral cortex is a rare and complex wonder, requiring special treatment and precise tuning. If you should own such an advanced melon, it is your responsibility to keep it running smoothly. Here's how.

BIG BRAINS CRAVE ALGAE AND ACID

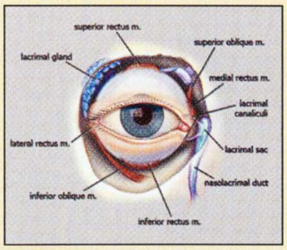
Algae with the cell wall removed contains amino acids that are the building blocks of healthy nerve cells and neurotransmitters that enhance big-brain function. In addition, Omega 3 and Omega 6 fatty acids help replenish lost brain cells. Food sources include cold-water fish like salmon and mackerel, walnuts, green leafy vegetables and cold-pressed sunflower oil. Note: These brain-loving foods can be found regularly in the cafeteria at Google Labs.

GET YOUR NAP ON

Everybody needs sleep, but for those well-endowed in grey matter, zzzzzz's are even more important. During REM sleep, the brain integrates information it took in during the day but couldn't process at the time. Taking a 20-minute nap can improve performance and self-confidence. Note: Google Labs' engineers may take catnaps whenever necessary, provided they refrain from drooling on their keyboards.

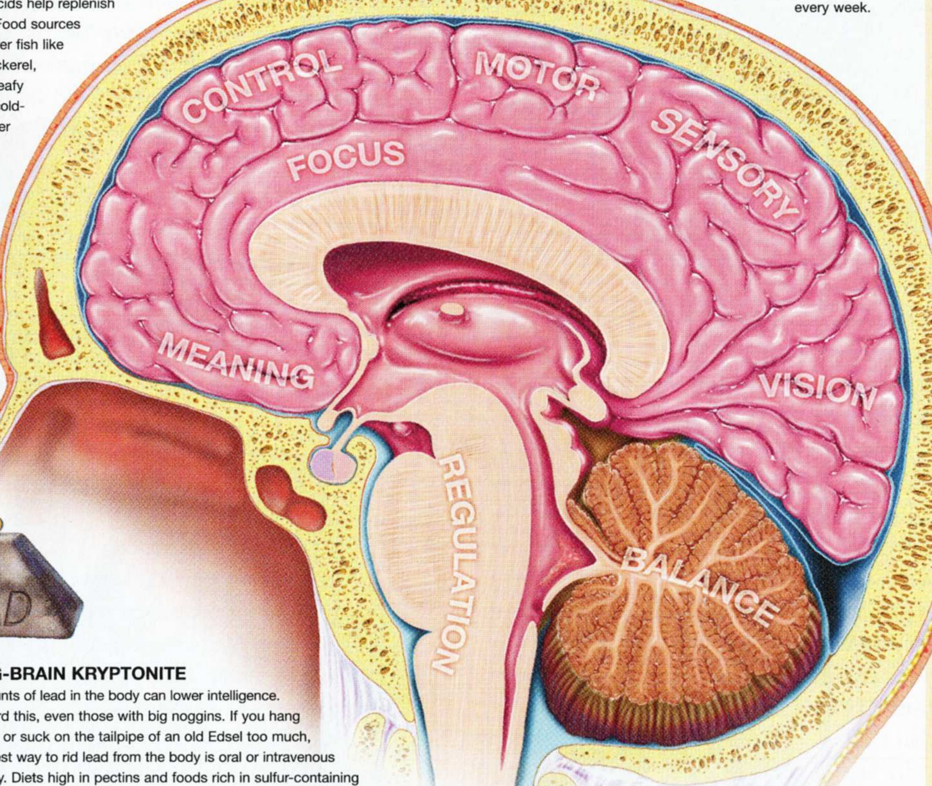
TAKE A WALK WITH YOUR BRAIN

Exercise increases heart rate so that more blood flows to the brain, enhancing energy production and waste removal. Because walking is non-strenuous, the leg muscles do not rob extra oxygen and glucose from your large brain – making it the ideal activity to clear out the cobwebs. FYI: A group "wetlands walk" departs out of The Mountain View headquarters of Google Labs every week.



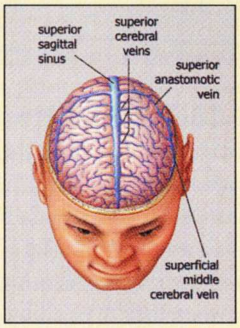
CRY, LAUGH AND ROCK OUT

Whether your brain is a behemoth or not, stress can damage. So crack up. Belly laughs release pain-killing endorphins, make you feel good and reduce stress. Cry. Tears of joy can scrub off adrenaline and other stress-related chemicals. Rock on. Tunes that suit your fancy have a sonic effect on your parasympathetic nervous system and shift your brain into chill mode. Incidentally, all of these stress-balancing outbursts are applauded by others at Google Labs.



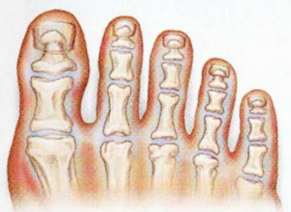
LEAD IS BIG-BRAIN KRYPTONITE

Even small amounts of lead in the body can lower intelligence. No one can afford this, even those with big noggins. If you hang around old paint or suck on the tailpipe of an old Edsel too much, know that the best way to rid lead from the body is oral or intravenous chelation therapy. Diets high in pectins and foods rich in sulfur-containing amino acid can also help. Note: Google Labs is a lead-free work environment.



COOLER BRAINS PREVAIL

Before the human brain could evolve greater mass and density, a "radiator" network of cranial veins had to evolve. In other words, efficient brain blood-flow was absolutely necessary to the development of higher intelligence – then and now. The bigger and higher performance the mind, the hotter it will run. So keep it cool. Drink lots of complimentary, icy beverages such as those available 24/7 for staffers at Google Labs.

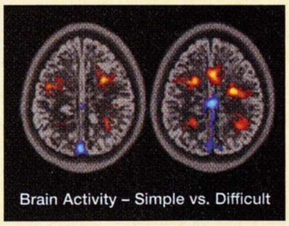


WAKE UP TO YOUR LARGE CEREBELLUM

Bigger brains need more warm-up time. So before you rise each morning, rouse your little piggies first. Wiggling your toes activates nerves that stimulate your brain and internal organs – helping you become bright-eyed, bushy tailed and ready to show the world just how smart you are. (Toe wiggling is easily accomplished at Google Labs, and sandal-wearing is encouraged.)

SHARE YOUR BIG BRAIN WITH THE WORLD

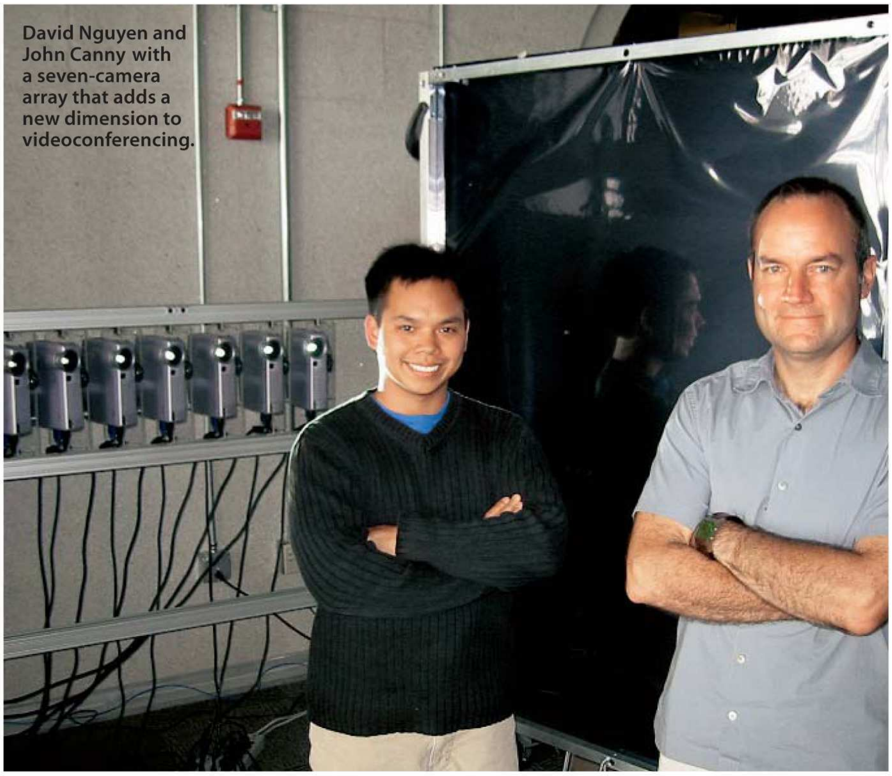
Big brains are at their best when they are able to share their gift with everyone. So apply for a position with Google Labs. You and your killer brain will work on some of the most challenging and rewarding projects on earth. And spend 20% of your time working on projects of your own – in a culture that encourages you to use both sides of that big grape. Email your resume to bigbrain@google.com or check out google.com/labjobs



Brain Activity – Simple vs. Difficult

USE YOUR BIG BRAIN OR LOSE IT

Even those equipped with an advanced big brain must use it or lose it. So challenge your wrinkly friend to learn new tasks, especially processes that you've never done before. Examples include square-dancing, tai chi, yoga, or impossibly difficult engineering problems. There is an abundance of challenging tasks for engineers at Google Labs, by the way. Plus yoga classes on Wednesdays.



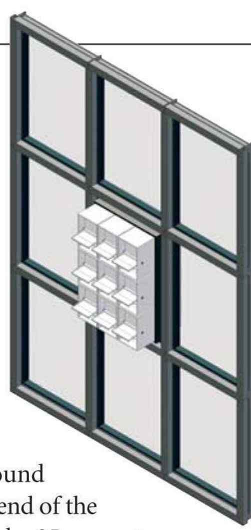
David Nguyen and John Canny with a seven-camera array that adds a new dimension to videoconferencing.

3-D CONFERENCING

WATCHING 3-D VIDEO USUALLY MEANS DONNING A GEEKY PAIR OF COLORED OR polarized glasses—not the kind of fashion statement you want to make at the office. But at the University of California, Berkeley, computer scientists David Nguyen and John Canny are building an office videoconferencing system that adds a third dimension to ordinary streaming-video images, no glasses required. "The dynamics people have when they're working in the same room"—who's looking at whom, for example—"are all taken away when you meet over a 2-D videoconference link," says Nguyen. So he and Canny built an array of seven cameras, each with a slightly different view, that link via a computer to seven video projectors. A special, multilayered screen focuses the light from each projector so that a viewer's right and left eyes receive images from adjacent cameras, creating a stereo effect. The pair plan to finish a prototype they can show to potential licensees by the end of 2005.

FRESH AIR

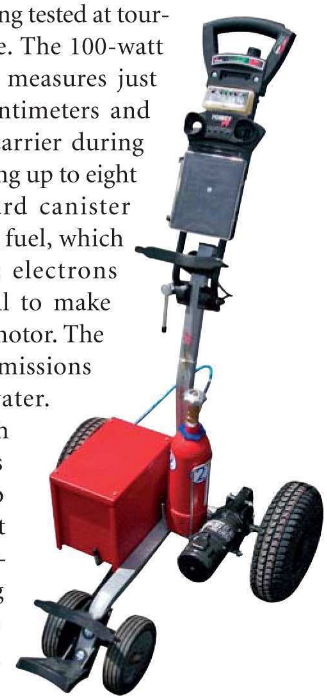
A NEW DEVICE MAY BRING FRESH AIR to people who live or work in city buildings—without letting in the noise from traffic. Developed by Chris Field, senior acoustic consultant at the Sydney, Australia, offices of engineering firm Arup, and Fergus Fricke, honorary associate professor at the University of Sydney, the polycarbonate brick has a channel cut through it that allows air to flow through. To stop street noise from doing the same, small tubular cavities lead off the channel. The air flowing over the mouths of the cavities causes them to resonate, creating small differences in pressure that scatter the sound waves, dissipating most of the traffic noise before it reaches the end of the channel. Field and Fricke claim the device cuts inbound noise by 85 percent, and they've licensed the technology to Silenceair in New South Wales, Australia.



Channels and chambers let air but not noise flow through this plastic brick.

FUEL CELLS TO THE FORE

GOLF CADDIES COULD SOON BE AT THE vanguard of the clean-energy movement. Engineering firm Soluções Racionais de Energia (SRE) of Torres Vedra, Portugal, has built a fuel-cell-powered golf bag carrier, which is being tested at tournaments in Europe. The 100-watt stack of fuel cells measures just 10 by 8 by 6.5 centimeters and has powered the carrier during rounds of golf lasting up to eight hours. An onboard canister supplies hydrogen fuel, which is stripped of its electrons inside the fuel cell to make electricity for the motor. The only significant emissions are droplets of water. When trials finish by the end of this year, SRE intends to ask an independent auditing firm to certify that the golf bag carrier meets international safety and quality standards so that it can go into production.



A green way to tote clubs on the green

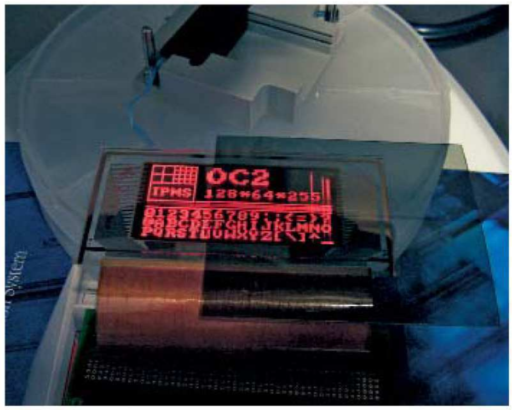
HERBICIDE HELPER

Researchers at the University of Texas at Austin have developed a chemical that could help farmers cut down on the hundreds of millions of kilograms of herbicide they spray on their fields each year. Plant cells defend themselves from herbicides using proteins that pump invading herbicide molecules out before they have a chance to do harm. The researchers' chemical, which would be combined with a conventional herbicide, inhibits an enzyme that powers these proteins, slowing the pumps so that the herbicide has more time inside the cells to do its job. In one field test, the herbicide helper reduced by 50 percent the amount of a common herbicide called atrazine needed to keep a corn crop free of weeds. The university has licensed the technology to Entercel, a startup that aims, via partnership with an agricultural chemical company, to have a combination herbicide and booster product on the market within five years.

COURTESY OF CHRIS FIELD (FRESH AIR); GONÇALO DE MOURA ELIAS (FUEL CELLS); DAVID NGUYEN (3-D)

BRIGHT LIGHTS, LITTLE BATTERY

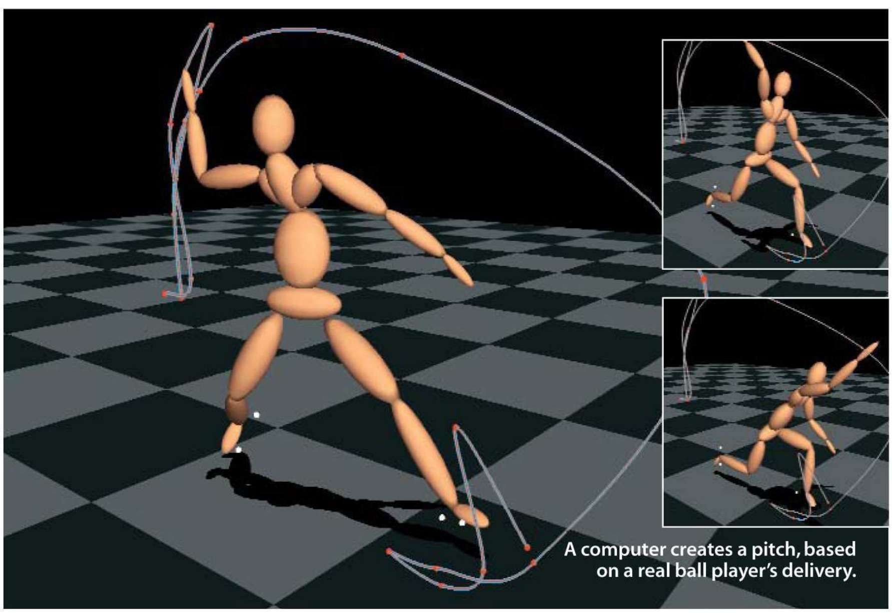
ORGANIC LIGHT-EMITTING DIODES HAVE BEEN TOUTED AS A BRIGHTER AND LESS power-hungry alternative to the standard liquid-crystal displays found in cell phones and other devices. Novaled, a startup in Dresden, Germany, aims to make OLEDs even more attractive by doubling their energy efficiency. The Novaled researchers infuse the outer, organic, layers of the multilayer diode with small amounts of another organic material, in much the way that chip makers "dope" semiconductors. The added molecules boost the layers' electrical conductivity and thus reduce the amount of power the diode loses as heat. The company has already made a more energy-efficient green OLED, says CEO Gildas Sorin. It is close to doubling the efficiency of the red and blue OLEDs that would also be required for a full-color display, he adds. Novaled expects the first display containing its materials to hit the market by early 2006.



Organic light-emitting diodes shine in a tiny display.

A GREAT LISTENER

A new audio surveillance system could help fight crime in the city and protect kilometers of unmanned borders. Software developed by Ted Berger, director of the University of Southern California Center for Neural Engineering, can be trained to recognize and distinguish sounds that are indicators of a security breach or a safety hazard, such as a gunshot or the rattle of someone climbing a chain-link fence. The software is based on mathematical models that mimic the way the brain interprets sound, but it can distinguish between two similar sounds far more precisely than the human ear. This fall, Oak Brook, IL-based Safety Dynamics plans to implement the software in surveillance devices that monitor urban activity. Mounted on streetlight poles, the devices will listen for gunshots, then guide surveillance cameras toward the source of the sounds. Berger says the technology can also be used for large-scale security; an array of detectors placed along a deserted border, for example, could listen for footfalls or whispers, painting a scene solely on the basis of acoustic information. The detectors could then notify a central location of any suspicious activity.



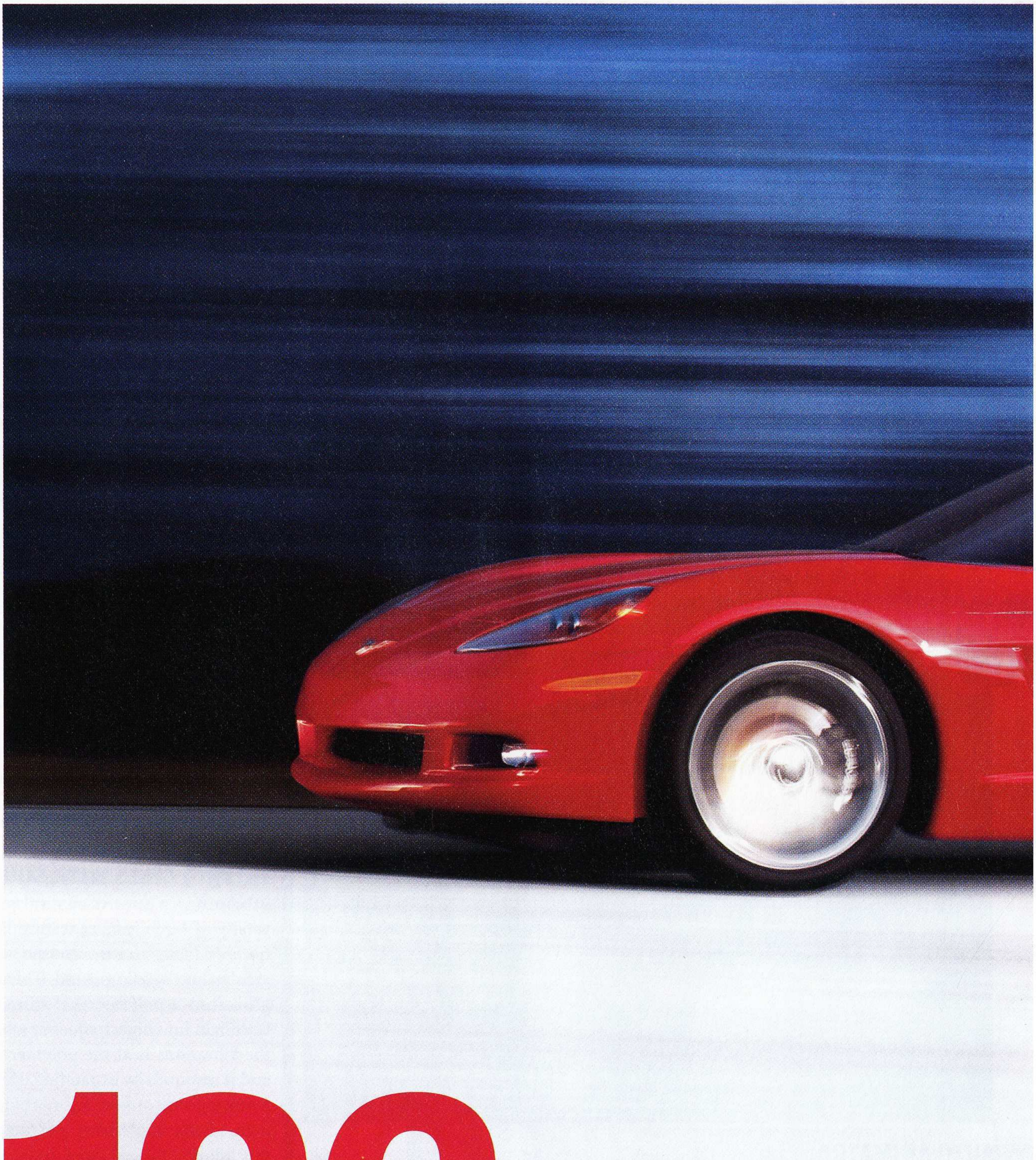
A computer creates a pitch, based on a real ball player's delivery.

AUTO ANIMATOR

ANIMATING A PERSON'S MOVEMENTS FOR A MOVIE OR VIDEO GAME CAN BE COSTLY and time consuming, requiring that actors be filmed with special cameras for every step and shrug. A new tool created by Zoran Popović at the University of Washington and Aaron Hertzmann at the University of Toronto, however, can extrapolate a person's movements from a single sequence of motions. First, the sequence is used to train the system. Then the animator picks a new movement for the digital character by, say, changing the position of its hands and feet. The system then calculates the most probable corresponding positions of the rest of the body. Popović says that a clip of only 20 or 30 frames is enough information to give the system a good sense of how a person tends to move. Popović imagines that the technology would be particularly useful for animators who make sports video games based on actual players. In fact, the technology is currently licensed to Redwood City, CA-based Electronic Arts, a maker of video games.

MOVING CELLS WITH SOUND

BIOMEDICAL ENGINEERS AT THE UNIversity of Michigan are testing "acoustic tweezers" that use ultrasound waves to gently shuttle cells around. The cells are grown on a polymer that turns pulsed laser light into high-frequency vibrations; the vibrations heat the polymer slightly, and it responds by expanding. Projecting a pulsing ring of laser light around a cell deforms the underlying polymer into a tiny hill, and the cell slides down its slope. Moving the laser nudges the cell in any direction. One advantage of the technique over other cell manipulation schemes is that the process can be reversed and an isolated cell returned to its place in the cell culture. Project leaders Matt O'Donnell and Tak Buma hope to initially license the technology to drug companies. Drug researchers could quickly isolate liver cells, say, treat them with potential drugs, and return them safely to their cultures to see if they suffer any toxic effects.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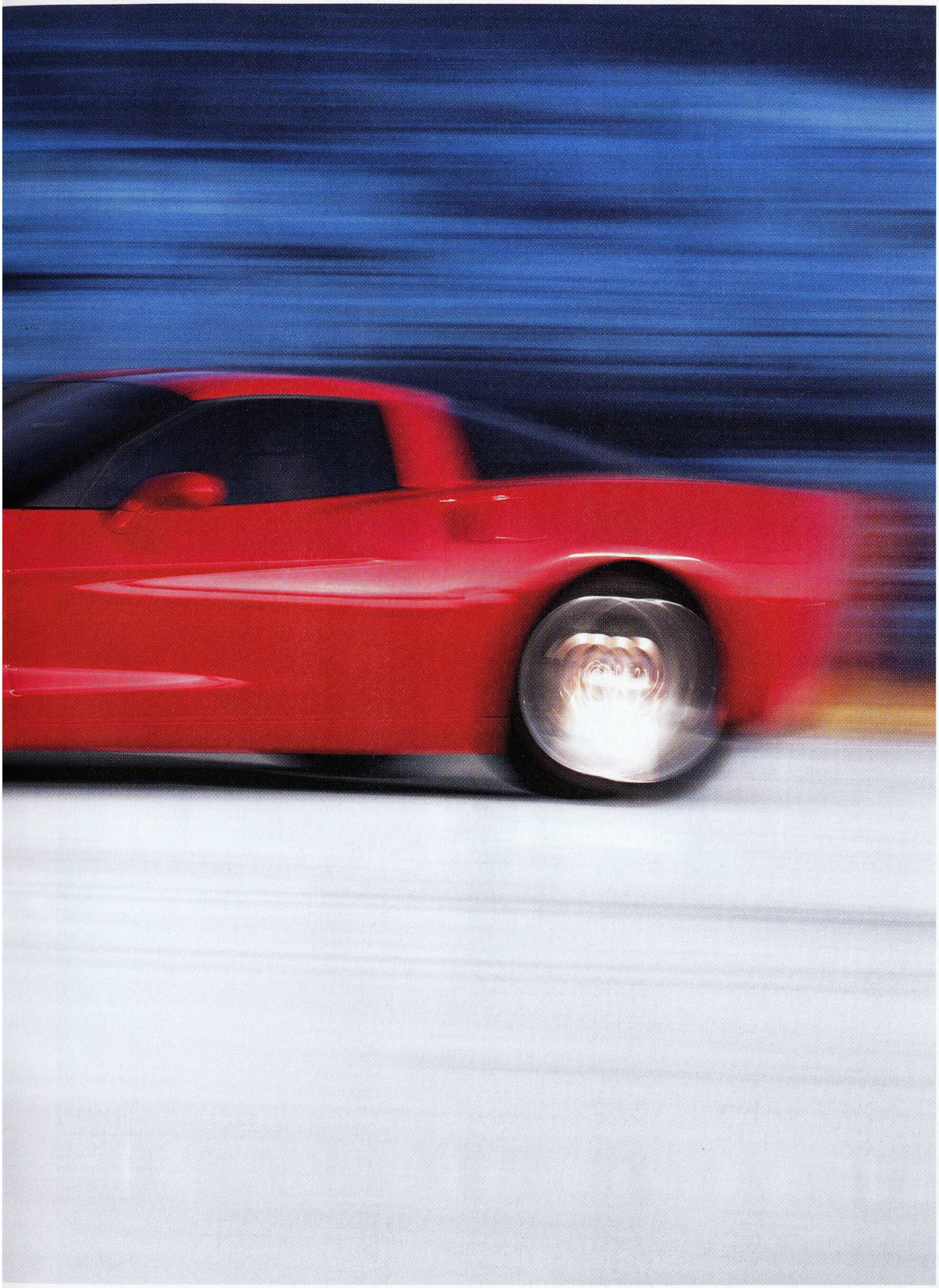

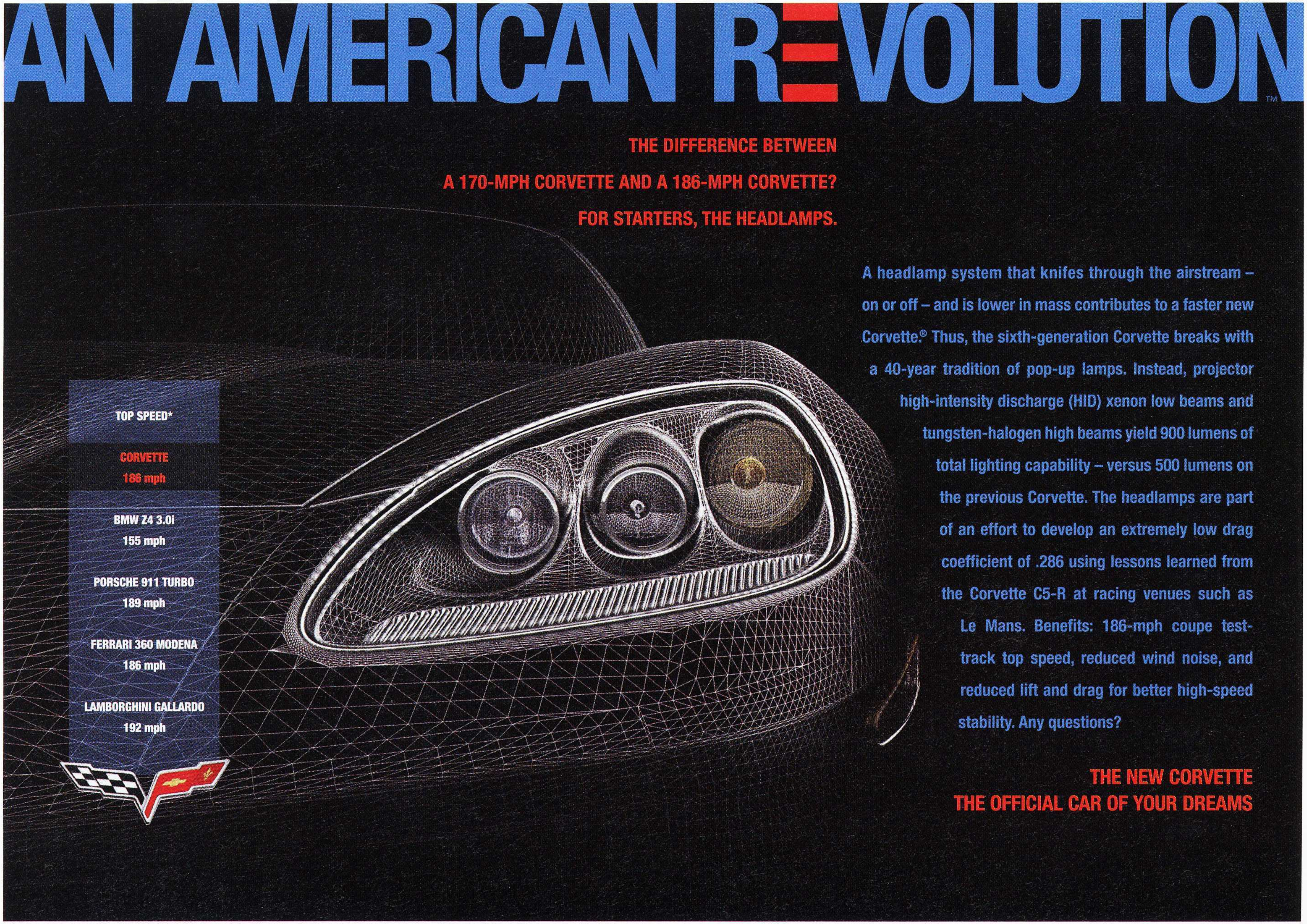
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192 mph

A Foot in the Doctor's Door

TAKE A GOOD HARD LOOK AT YOUR TOENAILS. ARE any of them flaky, yellow, and cracked? Then you, too, might be suffering from the heartbreak of onychomycosis. ▪ No smirking please. Onychomycosis is an ugly fungal infection afflicting the toes of more than 35 million Americans. On occasion, it can be excruciatingly painful. More commonly, however, the disease turns toenails into unappetizing strips of calcified decay. Yech.

But what makes onychomycosis so infectiously intriguing is not its tendency to attack toenails while leaving fingernails untouched, nor its stubbornness in taking root in nail beds. No, what truly makes this parasite provocative is its profitability. In barely seven years, treating onychomycosis has grown into a business worth hundreds of millions of dollars annually for Novartis, one of the world's largest pharma firms. Millions of people have paid roughly $1,000—more than $100 per infected toe—for pills made by Novartis that rid them of the evil fungus causing this unappealing condition. That's real money.

Remember, we're not talking baldness, depression, or erectile dysfunction here; we're talking toenails. "Toenail tech" is so utterly devoid of any charm or sex appeal that the ability to turn a toenail treatment into a fast-growth, high-margin business says something important about the nature of innovation.

Novartis's toenail triumph is particularly illuminating because its original innovation salvo seriously misfired. When the firm launched its first marketing campaign for its new drug Lamisil in 1997, it made a crucial analytical error that nearly condemned the medication to marginality. In the end, Lamisil's rebound and ultimate success required Novartis to ignore its most obvious selling point.

Novartis launched Lamisil with the advertising slogan "Let your feet get naked." As Lamisil brand director Christine Sakdalan puts it, "The most intuitive insight was this was a very ugly disease—it looks ugly and feels ugly. That was what the research way back when emphasized, and we went with it. That was the low-hanging marketing fruit for us."

A drug for toenail fungi may lack sex appeal, but after an initial stumble, Novartis turned it into big business.

The campaign succeeded in raising both consumer awareness and response. Unfortunately for Novartis, all this publicity failed dramatically to translate into the desired revenues. Why? Because the overwhelming majority of doctors didn't see beautiful "naked feet" as a medical goal worthy of their prescriptions.

"[After-launch] research revealed a fundamental disconnect between patients and physicians that needed to be closed," Novartis chief marketing officer Kurt Graves observed in a trade magazine article. "Patients didn't realize the cause of the condition or the potential seriousness. Physicians, who had never heard from patients about their nail condition, didn't believe it was a problem and saw it more as a cosmetic issue that could be self-managed or treated with over-the-counter medications." In other words, Lamisil's future commercial success depended less on the patient's aesthetic desires than on the physician's perception of medical need.

Consequently, Novartis completely repacked, repositioned, and remarketed Lamisil. Beauty became the happy byproduct of Lamisil's new promise: killing a stubborn and potentially painful fungal infection. Doctors were asked to be doctors treating an infectious threat rather than beauticians preparing people for summer's barefoot strolls. Not incidentally, stressing the medical over the cosmetic elements helped many possible Lamisil users feel less self-conscious about complaining to their physicians about tender toenails.

The clearest indication that the repositioning was succeeding came when the female-to-male ratio among Lamisil users quickly shifted from 70:30 to 50:50. Men typically care far less about how their toenails look than women do. Decosmeticizing Lamisil made it a more "serious" medication for doctors to prescribe.

The cynical interpretation of Lamisil's success is that creative advertising and promotion can turn even a toenail therapy into a bestseller. There's almost a billion dollars' worth of truth in that. But as with Lamisil's initial marketing campaign, the obvious conclusion is misleading.

The better story here is that Novartis corrected a huge marketing innovation error by learning—and relearning—that it needed to appeal to the medical community's sense of professional self, not just the Lamisil user's sense of vanity. In truth, the most important learning about innovation adoption almost always takes place *after* a product has been launched—not before. More often than not, innovators discover the real obstacles to their success—and the opportunities for growth—months or even years after introducing a new technology.

Does Lamisil represent a medical breakthrough for innovators to emulate? Absolutely not. But the ability to innovatively rebrand, reposition, and profitably rechannel a $1,000 medication for toenails most assuredly does. TR

A researcher and consultant on innovation economics, Michael Schrage is the author of *Serious Play* (Harvard Business School Press, 2000).

Why WiMax?

A new metropolitan-area wireless standard will change the economics of Internet access—again. **BY WADE ROUSH**

It's hard to buy a laptop computer today that doesn't come with a Wi-Fi chip: a built-in radio that lets users surf the Web wirelessly from the boardroom, the bedroom, or the coffee bar. People love Wi-Fi because a single base station—a box with a wired connection to the Internet, such as a DSL, cable, or T1 line—can broadcast to multiple users across distances as great as 100 meters indoors and 400 meters outdoors. But there's a new technology standard on the way that will make Wi-Fi look feeble. It's called WiMax, and it provides wireless broadband Internet connections at speeds similar to Wi-Fi's—but over distances of up to 50 kilometers from a central tower.

"Metropolitan area" wireless networking at broadband speeds isn't new, but the specialized equipment that receives the broadband signals has typically been too expensive for everyone but large businesses. Now that U.S. computing and communications firms are gradually reaching consensus on the details of the WiMax standard, however, those prices could come down significantly. Industry agreement on details such as how to encrypt WiMax signals, which frequencies to use, and how to provide multiple users with access to

JOHN RITTER

those frequencies will finally allow companies like Intel to manufacture mass quantities of WiMax-enabled chips for use in broadband wireless equipment. And that's expected to eventually bring WiMax receivers into the $50 to $100 price range of today's DSL and cable modems, meaning that millions of users could eventually drop their current Internet service providers—often local phone or cable companies—and simply access the Internet over rooftop antennas at the other end of town.

Millions of home broadband users could drop their DSL or cable providers and simply access the Internet by antenna.

WiMax's first appearance, however, will take place in more public venues. Equipment meeting the standard will allow a new wave of small and medium-sized businesses to go wireless, abandoning the expensive T1 lines they currently rent from local or regional phone companies. New Wi-Fi base stations designed to connect to the Internet via WiMax could also create mobile-computing hot spots in places without phone lines—think the Great Lawn in Central Park. And WiMax networks could extend broadband Internet access to poor regions that currently have none.

WiMax—an acronym for Worldwide Interoperability for Microwave Access—is little more than a long list of technical specifications intended to ensure that wireless equipment from different vendors can interoperate at high speeds. Also known as 802.16, the specifications have been under development since the 1990s as an alternative to technologies such as Ethernet and Wi-Fi. A single WiMax transmitter will transmit voice, video, and data signals across distances of up to 50 kilometers (assuming an unobstructed line of sight) at rates as high as 70 megabits per second—enough to support about 60 businesses at T1 speeds, or hundreds of homes at DSL speeds.

It was Intel's announcement of a major push into WiMax technology in January 2004 that helped the standard emerge into the spotlight. The company's Centrino initiative had already put Wi-Fi chips into millions of laptops. "After we did that, we began looking at whether you can cover full cities with Wi-Fi," explains Scott Richardson, manager of Intel's broadband wireless group. While it would be relatively simple to blanket an entire city with Wi-Fi hot spots, the company decided, such a patchwork would be difficult to administer and would operate over too narrow a frequency range to deliver sufficient amounts of data for future needs. "We came to the conclusion that Wi-Fi needed to evolve into more of a 'carrier' technology, deployed by a service provider, and needed to exploit a lot more spectrum options," says Richardson. WiMax, which operates at greater distances and over a greater range of frequencies, turned out to be ideal.

The company began designing communications processors to exploit these frequencies—from roughly two to 11 gigahertz, a range used mainly by Wi-Fi, microwave ovens, and certain types of radar—and had delivered the first sample chips to manufacturers by September. Meanwhile, it began promoting an industry association called the WiMax Forum to certify equipment from vendors as WiMax compliant. And through Intel Capital, the company's venture wing, it has begun to make strategic investments in a few companies that plan to demonstrate how WiMax can be put to profitable use.

Seattle-based Speakeasy is one of those companies—and a prime example of the economics driving WiMax's rollout. Founded in 1994 as an Internet café, Speakeasy has evolved into the leading provider of extrafast DSL connections to hard-core online gamers and technical professionals who work at home. But because DSL works over phone lines, it has an inherent limitation: about 30 percent of residences in the cities Speakeasy serves are too far away from phone network central offices to get a usable signal. "That's a lot of people to turn away," says Speakeasy CEO Bruce Chatterley. "That's why we started to look for alternatives, and that's why WiMax is so strategic to our business." Speakeasy will begin technical trials of WiMax equipment using Intel's chips by the end of this year and hopes to offer broadband wireless connections to business and residential customers by the middle of 2005.

But while the emergence of WiMax will give consumers, businesses, and people in hard-to-reach areas a powerful new way to connect to the Internet, it won't happen overnight. For one thing, it could take manufacturers some time to reach the economies of scale that would enable consumer-priced WiMax equipment. Then there's the cost of building a network of transmitters. "People tend to think that you can put one WiMax tower on a hillside and beam around the entire city, and that's certainly not the case," says Intel's Richardson. "When you fill up a cell, you use up the capacity"—meaning that providers will still have to add towers as demand grows, just as they do in traditional cell-phone networks.

But TowerStream, a Waltham, MA, company that plans to add WiMax to its existing broadband wireless services, thinks it has that problem licked: it's already tied up what chief operating officer Jeff Thompson calls "beachfront property" atop many of the tallest buildings in Boston, New York City, Chicago, and other cities, and it will simply install the new WiMax-certified gear alongside its existing transmitters. "When WiMax comes out," Thompson says, "our speed of deployment will be very quick. We'll have a wireless backbone in the sky." Which sounds great—as long as it really does cost less to use than our earthbound skein of wires, fibers, and cables. TR

Engineers are giving Robonaut a keener sense of its own movements.

ROBOTICS

Adroit Droids

After 50 years of research, scientists have yet to build a robot that can learn to manipulate new objects as proficiently as a one-year-old child. Robots don't react well to new situations; most of their movements must be programmed in advance. Some use sensors to fine-tune their movements in real time, but they generally don't retain and interpret the sensor data. So while they might navigate a room without bumping into things, they can't stop to help rearrange the furniture.

But now advances in sensors, software, and computer architecture are beginning to give robots a sense of their "bodies" and of what sorts of actions are safe and useful in their environments. The results could eventually include more effective robotic assistants for the elderly and autonomous bots for exploring battlefields and space.

This summer, one of the world's most advanced robots passed an important test at NASA's Johnson Space Center in Houston, TX. The dexterous humanoid robot learned to use tools to tighten bolts on a wheel. Rather than having to be separately programmed for each of several possible situations, the robot showed it could recover if a tool slipped from its grasp or was moved around—and that it was flexible enough in its routine to tighten the bolts in any order requested. "Now, within limits, the robot can adjust to changes in its environment," says Vanderbilt University electrical-engineering professor Alan Peters, one of the project leaders.

The key advance: a new framework for robot learning. Peters's software gives the NASA robot, called Robonaut, a short-term memory that lets it keep track of where it is and what it's doing. By correlating actions like reaching for and grasping a tool with information from its 250 sensors—visual, tactile, auditory—the robot gets a feel for which movements achieve what kinds of goals. It can then apply that information to the acquisition of new skills, such as using a different tool. Maja Mataric, codirector of the University of Southern California's Robotics Research Lab, calls Peters's work "important for bringing together research on sensory-motor learning and applying it to real-world, highly complex robots." **Gregory T. Huang**

MEDICINE

Modular Drugs

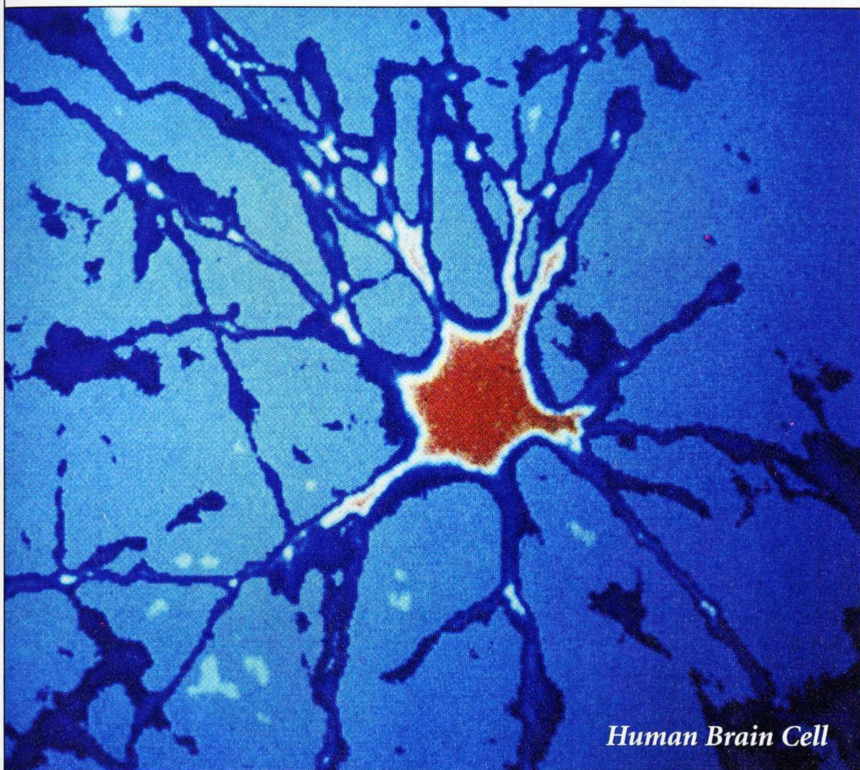
Over the past decade, biotech companies have introduced a string of protein-based antibody drugs, which mimic the action of the body's own immune system to combat conditions like cancer and arthritis. Antibody drugs can zero in precisely on misbehaving cells and often enlist the aid of our own antibodies to force a disease into retreat. But there's a price for their effectiveness. Antibody drugs are based on large molecules, so they have a hard time getting into the bloodstream and into cells.

Over the past year, however, researchers have begun to test a new class of genetically engineered protein drugs that act like antibody drugs but are more easily absorbed into the body. They're called small modular immunopharmaceuticals, or SMIPs, and their main proponent is Seattle-based Trubion Pharmaceuticals. "The basic idea was, 'How do we make these molecules smaller'" without diminishing their effects? says Daniel Burge, Trubion's senior vice president of clinical development.

The drugs Trubion's researchers eventually devised are one-third to two-thirds the size of conventional antibody drugs. They can also be adapted to the needs of specific patients: sections of the molecules can be added or removed to hit offending cells with larger or smaller payloads, depending on the treatment required.

Trubion's most advanced drug, which will enter safety trials in humans early in 2005, attacks white blood cells called B cells, which can cause diseases like lymphoma and leukemia when they become malignant. One end of the drug molecule binds specifically to B cells, while the other end carries a module that invites other immune cells to attack the B cells. Nancy Haigwood, viral-vaccines program director at the Seattle Biomedical Research Institute, says that based on the data she has seen on Trubion's drugs, "It's possible that for particular applications they might even replace [current antibody drugs] because they are smaller, nimbler, and better at getting to the cells. It looks like it has terrific potential." **Karen Epper Hoffman**

Slow Down The Clock On Your Aging Cells.

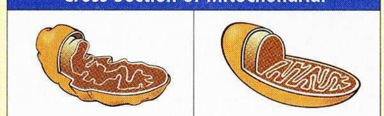


Human Brain Cell

Healthy Cells Need Healthy Mitochondria.

A central factor in aging is the decay of the mitochondria in your cells. These are the biological engines that convert fats and sugars into energy. Aging mitochondria cannot take in as much fuel, so they produce less energy and more oxidant toxins.

Cross Section of Mitochondria.



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[1] *Read more about this scientific team's discoveries in "The Proceedings of the National Academy of Sciences," February 19, 2002. Find these articles and others at www.juvenon.com.*

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IMAGING

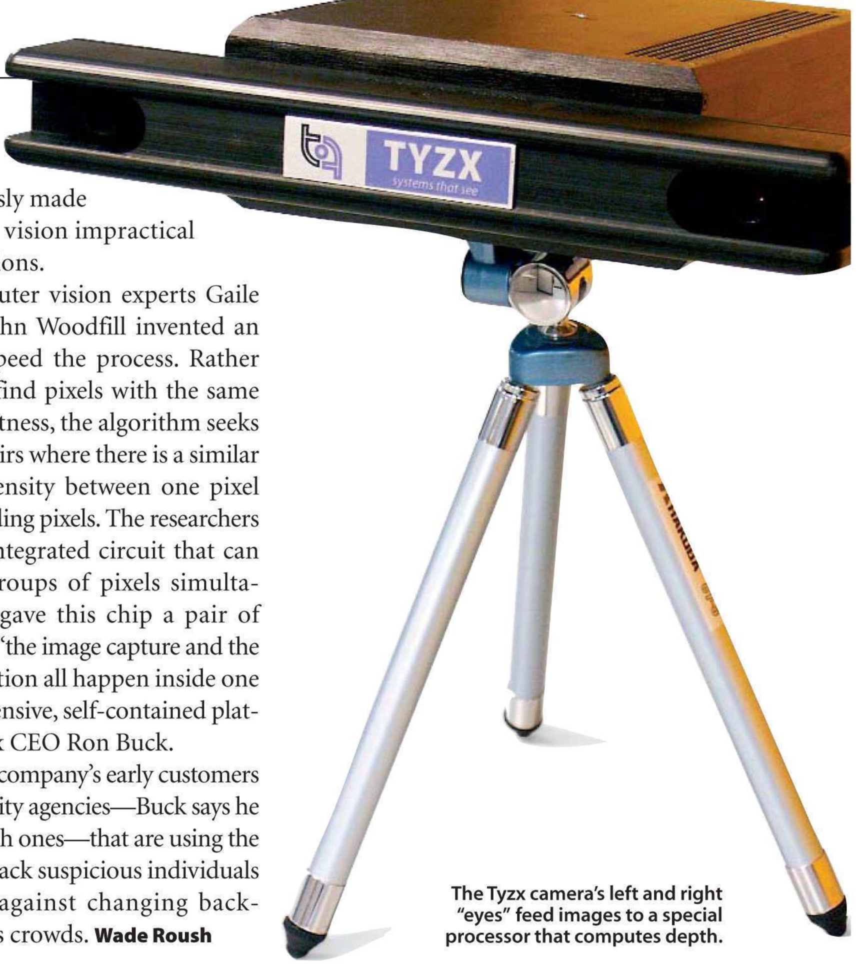
Deeper Vision

Researchers are making big strides toward low-cost systems that mimic human vision to give machines three-dimensional information about their environments. By building hardware that analyzes corresponding chunks of paired live images in parallel—as the human brain is thought to do—Tyzx, a startup in Menlo Park, CA, is making computerized depth perception fast enough that surveillance devices and robotic vehicles can incorporate it.

Creatures with two forward-facing eyes can perceive depth because their left and right eyes see from slightly different perspectives, in which the displacement of nearby objects is greater than that of distant objects. Using this apparent difference, called parallax, the brain swiftly determines the distance to an object. While a machine equipped with a pair of cameras can also use parallax to see in three dimensions, the amount of computation required to find matching pixels had previously made stereo machine vision impractical for most situations.

Tyzx computer vision experts Gaile Gordon and John Woodfill invented an algorithm to speed the process. Rather than trying to find pixels with the same color and brightness, the algorithm seeks out left-right pairs where there is a similar contrast in intensity between one pixel and its surrounding pixels. The researchers then built an integrated circuit that can search many groups of pixels simultaneously. They gave this chip a pair of "eyes," and now "the image capture and the stereo computation all happen inside one relatively inexpensive, self-contained platform," says Tyzx CEO Ron Buck.

Among the company's early customers are federal security agencies—Buck says he can't reveal which ones—that are using the technology to track suspicious individuals as they move against changing backgrounds such as crowds. **Wade Roush**



The Tyzx camera's left and right "eyes" feed images to a special processor that computes depth.

MEDICINE

Screening with Sound

There's a well-established medical technology that many physicians believe could help catch undiagnosed breast tumors in one-third to one-half of women—yet it's not being used routinely. It's ultrasound imaging, a longtime fixture of obstetricians' offices. Some doctors use ultrasound along with traditional x-ray mammography in breast exams, but the majority have been waiting for clearer evidence of its benefits. And that's exactly what a key clinical trial now under way in the United States could provide.

At least half of women under 50 and about a third of older women have naturally dense breast tissue, making it harder to distinguish between healthy tissue and questionable masses in mammograms. Ultrasound can get around that problem because the different types of tissue reflect sound waves differently, says Wendie Berg, the leader of the trial and an independent breast-imaging consultant in Lutherville, MD. "Ultrasound is widely available and relatively inexpensive," she says. "It's reasonable to consider it for routine screening."

Ultrasound can reveal tumors missed by mammograms.

In past studies involving thousands of women, ultrasound did detect dozens of dangerous cancers missed by mammograms. But the studies didn't adequately measure the reverse: the number of cancers detected by mammograms but missed by ultrasound.

The new trial will assess 2,808 women at 20 different U.S. and Canadian locations over three years and is designed to count "false negatives" accurately. All participants will get ultrasound exams in addition to their annual mammograms. A final verdict on the two technologies' effectiveness isn't expected until 2008.

Oncologists say ultrasound would only be a supplement, not a replacement, for x-ray mammography, since both methods sometimes miss tumors and misidentify healthy tissues as cancerous. But the two together, says Berg, could catch more cancers than mammography alone. **Corie Lok**

COURTESY OF CMSP (SCREENING); COURTESY OF TYZX (VISION)

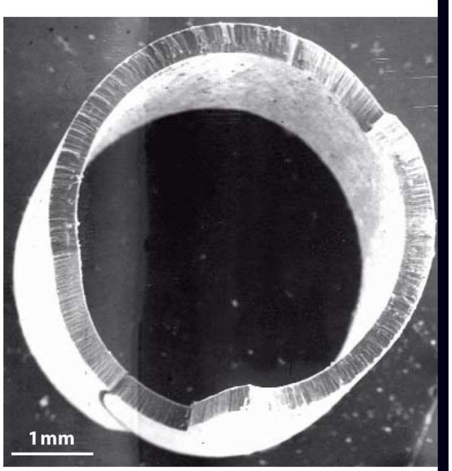
NANOTECHNOLOGY

Nanofilters

Every day, an estimated 3,000 to 6,000 people worldwide die from diseases caused by contaminated water. Filtration can reduce the risks, but traditional bacterial and viral filters trap pathogens inside granular carbon or porous ceramic or polymer materials, many of which are difficult to clean and must be changed frequently.

Now scientists are turning to carbon nanotubes. A team from Rensselaer Polytechnic Institute in Troy, NY, and the Banaras Hindu University in Varanasi, India, has devised a way to get millions of the large carbon molecules to collect on the inside surface of a quartz tube about a centimeter across. The resulting tube-inside-a-tube consists of radially oriented nanotubes, packed as tightly as a fistful of spaghetti and bonded together; this structure can be detached from the quartz and extracted whole. With one of its ends capped and water pumped in through the other, such a cylinder acts as a filter. Water molecules can squeeze out through nanometer-sized gaps in the walls, but bacteria like *E. coli* and viruses like the 25-nanometer-wide poliovirus get stuck.

The structures are heat resistant and strong enough that they can be cleaned repeatedly using autoclaves or ultrasound devices like those at medical clinics and hospitals, making them reusable many times, says Pulickel M. Ajayan, the professor of materials engineering at Rensselaer who led the work. David Cotriss



Tightly packed nanotubes form a cylinder.

COURTESY OF PULICKEL M. AJAYAN (NANOFILTER); COURTESY OF PARAMOUNT'S GREAT AMERICA (TAGS)

At Paramount's Great America, a network of receivers tracks kids wearing radio frequency ID tags.

WIRELESS

Wrist Radio Tags

CONSUMERS ARE GETTING USED to the idea that nearly all products, packages, or pallets of merchandise will soon bear radio frequency ID tags to help manufacturers and retailers manage inventory. But sooner than most people realize, they may be wearing such tags themselves: a few amusement parks, hospitals, and even schools are pressing ahead with projects to put RFID tags into wristbands to keep track of patrons, patients, and students.

The technology makes medical care safer and more efficient. Staff at the 30-bed general surgery unit at the Jacobi Medical Center in New York, NY, for instance, are outfitting patients with RFID wristbands that record their names, genders, dates of birth, and chart numbers—the codes for their electronic medical records. Doctors and nurses use tablet PCs equipped with RFID readers to upload this data from a patient's wristband, and the computers then retrieve the patient's record wirelessly from the hospital database. "We're hoping we will eliminate the potential danger of giving the wrong medication to the wrong patient," says Robert Sidlow, associate medical director for the North Bronx Health Care Network. Sidlow hopes to install the RFID system in Jacobi's new 500-bed building, opening later this year.

RFID has also found a place in amusement parks. At Paramount's Great America in Santa Clara, CA, $5 will get a parkgoer an RFID bracelet encoded with his or her first name. One of 65 antennas scattered throughout the park—whichever is closest to the person at any given moment—reads the bracelet information and sends it to the park's central servers. Parents who lose their children can go to any of several kiosks, wave their own bracelets in front of the kiosks' readers, and bring up maps showing their kids' locations.

Not everyone is amused by such applications. While tracking and identifying people has obvious benefits, slapping RFID tags on people could infringe on their privacy if the technology is misused, warns Kenneth Farrall of the Electronic Privacy Information Center in Washington, DC. Though Farrall admits that the early applications of RFID tagging seem to do more good than harm, he cautions that as the technology grows more sophisticated, "it could become more difficult to control the data." **Corie Lok**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Insects such as water striders can walk on water—and now robots can too. Metin Sitti, an engineering professor who heads **Carnegie Mellon University's Nano-Robotics Lab**, has built an eight-legged mechanical creature that's so light—about one gram—that it can stand on water and propel itself forward without breaking the water's surface. Equipped with tiny sensors, Sitti says, future water-striding robots could be used to monitor water quality or snoop on enemies.

advance

Traditional cell phones have so few keys that typing text messages is a hassle, but PDAs with full Qwerty keyboards have so many keys that each one is tiny. The latest smart phone from Waterloo, Ontario, handheld manufacturer **Research in Motion**, the Blackberry 7100t, splits the difference with a 20-key keyboard. Most of the keys have two letters, and the phone's software guesses which one the user intends by reading previous letters and searching a 30,000-word internal dictionary. The software uses corrections, word frequency, and the user's address book to improve its predictions over time.

setback

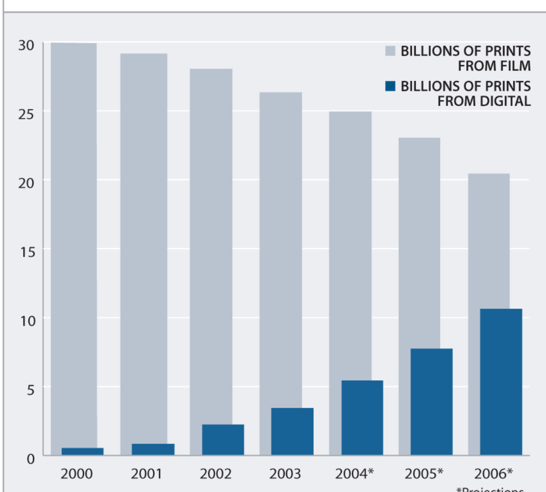
Longhorn, Microsoft's successor to its three-year-old Windows XP operating system, won't be ready for launch until 2006, the company said in August. That's more than a year later than originally projected, and it means rival operating systems such as Linux will have more time to get footholds before Microsoft upgrades its flagship product. At the same time, Microsoft said one much vaunted feature of Longhorn—a storage system called WinFS that will let programs such as Outlook, Word, and Excel share data more easily—won't be included in the operating system's first release after all.

record

Most Wi-Fi hot spots are no larger than your neighborhood Starbucks. But in the state of Washington, **Columbia Energy**, a subsidiary of one of the state's oldest rural electric cooperatives, is using the wireless technology to bring high-speed Internet service to underserved rural areas. It's creating what could be the world's largest area with continuous Wi-Fi coverage: a 9,600-square-kilometer area spreading across parts of Walla Walla, Columbia, and Umatilla Counties.

acquisition

Qualcomm, the San Diego–based maker of communications chips for cell phones, has agreed to pay $170 million to acquire **Iridigm**, a San Francisco company developing microelectromechanical displays for mobile devices that work on the same principle as the iridescence of a butterfly's wing. Qualcomm says it hopes to speed up commercialization of Iridigm's displays, which should cost less to manufacture than the conventional liquid-crystal displays found in most cell phones and PDAs.



«metric

With a digital camera, you don't have to get film developed to see how your pictures came out. Nonetheless, a growing number of U.S. amateur photographers are ordering prints of their digital photos—meaning steady business for photofinishers despite a big drop-off in sales of traditional film.

SOURCE: PHOTO MARKETING ASSOCIATION (METRIC); COURTESY OF METIN SITTI (MILESTONE)

ALL HYBRIDS ARE NOT CREATED EQUAL.

HYBRID

Unlike the competition's mild hybrids, which always require power from the gasoline engine, full hybrids – like the new Ford Escape Hybrid – have the ability to drive in electric-only mode at certain speeds. That means less trips to the gas station. 61% fewer smog-forming pollutants. 80% better fuel economy.* In fact, this SUV is the most fuel-efficient SUV out there. No, all hybrids are not created equal. On the road to a better future, some are born to lead the way. Fordvehicles.com/escapehybrid.

Ford

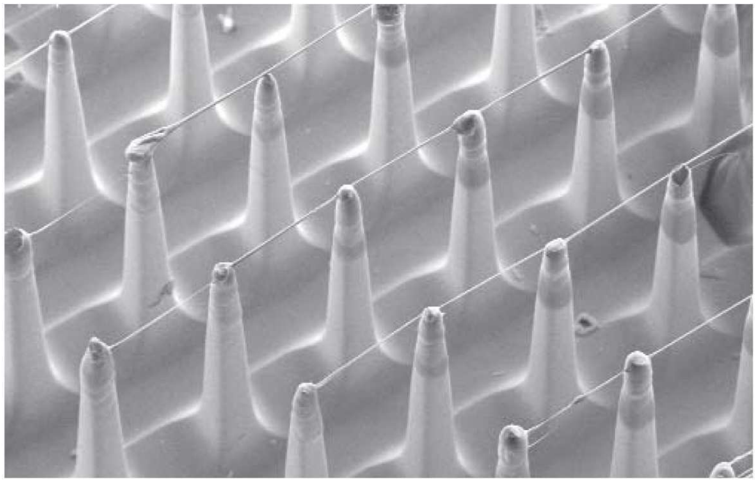
ESCAPE HYBRID

Earth's First Full Hybrid SUV.

*Improved fuel economy and emissions data compared to Escape gasoline engine. Escape Hybrid EPA estimated 36 city/31 hwy mpg, front-wheel drive. Your actual mileage will vary depending on your driving habits.

follow-up

Recent breakthroughs in materials science have sparked considerable excitement about the commercial feasibility of polymer-based solar cells that would be cheap and easy to make *(see "Solar-Cell Rollout,"* TR *July/August 2004)*. In a move that will combine two of the leading research groups in the field, **Konarka Technologies**, a Lowell, MA-based startup, has acquired Siemens's organic-photovoltaics business; Siemens's solar-cell researchers will also join Konarka. Last year, Siemens's scientists reported making polymer solar cells with record-setting efficiencies in converting sunlight to electricity.



research

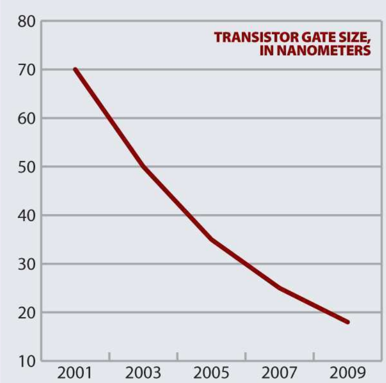
Scientists at the **University of Louisville** in Kentucky have developed a novel technique that could make it possible to more easily and directly form 3-D networks of nanostructures. The researchers use tiny tips to suspend fibers on micro- and nanostructures, providing a potential fabrication tool for microfluidic and microoptical devices.

advance

IBM scientists have measured the energy it takes to "flip" the magnetic orientation of a single atom. This measurement of one of the fundamental magnetic properties of materials is a significant step in developing nanometer-scale magnetic structures for ultradense data storage, quantum computing, and other advanced applications.

milestone»

Intel says that, in its effort to uphold Moore's Law, it has made a fully functional memory chip with more than a half-billion transistors, each measuring only 35 nanometers across. Intel expects to begin shipping commercial versions of the chip next year. Intel predicts it will be able to continue to shrink its chip technology through at least 2009 *(see chart)*.



Nano

funding

The **National Cancer Institute** has announced a $144.3 million, five-year initiative in nanotechnology. The research project will look to use recent advances in nanotech to improve the diagnosis and treatment of cancer.

manufacturing

One of the most intriguing properties of carbon nanotubes, large molecules that could prove a basic building block for nanotech, is their potential to form superstrong materials. Fibers made of nanotubes are potentially 10 times stronger than the strongest existing commercial fibers. Now researchers at **Rice University** say they have improved methods for manufacturing fibers made of single-walled carbon nanotubes. The improved manufacturing methods could potentially make large-scale production of the superstrong fibers commercially viable.

COURTESY OF ROBERT W. COHN (RESEARCH); SOURCE: INTEL (MILESTONE)

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Biote

milestone

The **European Commission** has given the green light for farmers throughout the European Union to buy and plant 17 varieties of genetically modified corn—the first time biotech crops have received such EU-wide authorization. All food made with the corn varieties, which St. Louis agricultural-products company Monsanto engineered to resist a pest called the corn borer, will be labeled as genetically modified.

ipo

Seattle's **Corus Pharma** has filed preliminary papers with the U.S. Securities and Exchange Commission for an initial public offering. Backed in part by Cascade Investment, Bill Gates's private fund, Corus is testing inhaled treatments for asthma and cystic fibrosis in humans.

acquisition

Palo Alto, CA's **Agilent Technologies** announced an agreement to acquire software firm Silicon Genetics of Redwood City, CA. The acquisition reflects an effort by Agilent—a leading maker of life-sciences and chemical-research equipment—to strengthen its position in bioinformatics.

regulations

Danvers, MA–based **Abiomed** has sought approval from the U.S. Food and Drug Administration to market its AbioCor artificial heart under a humanitarian-device exemption. Such an exemption would allow doctors to implant the heart, which has been tested on just 14 people so far, in not more that 4,000 patients suffering from end-stage heart failure.

advance

Researchers at **King's College London** have created human embryonic stem cells that carry a mutation that causes cystic fibrosis. The cells could offer new opportunities for scientists to study the devastating genetic disorder and develop new treatments for it.

ethics

As genetics researchers continue to home in on genes that affect behavior and contribute to neurological conditions such as schizophrenia and autism, Stanford University is launching a center to study the ethical consequences of such research. One project planned for the new **Center for Integration of Research on Genetics and Ethics**: a Web-based ethics consultation service for geneticists.

COURTESY OF ABIOMED

The Other Exponentials

ANY STABLE SYSTEM CAN BECOME UNSTABLE WHEN even one component experiences exponential growth. In information technology, this translates into opportunities for new research and new business models. ▪ Moore's Law—Gordon Moore's 1965 prediction that the number of transistors on a chip will roughly double every 18 months come rain or shine—describes infotech's most famous exponential growth factor. But there are many other infotech exponentials, and it's a good idea to think through their consequences.

Storage leaps to mind. In 2003, a $400 iPod had 10 gigabytes of memory. By early this year, a $400 iPod had 20 gigabytes of memory. If this annual doubling holds up, then 20 years from now we'll have portable devices with 20 petabytes of storage—that's 20 million gigabytes—sitting in our pockets. What might we want to do with all that storage, and what new services might it enable?

Want to see the future? Watch the multiples in storage capacity, sequencing speed, and wireless range and bandwidth.

The iPod is now big enough to contain the entire personal music collection of today's average listener. But the immediate consequence of storage growth is that our personal music collections will grow as well. CDs will no longer be a practical way to distribute content; they will go the way of wax cylinders and vinyl platters. That's why so many companies are rushing in to follow Apple in the music content download and management business.

Before too long, CD readers and writers will disappear from personal computers, just as floppy disks have already become obsolete. Flash memory cards are one possible successor, but today's versions are too slow and aren't cheap enough to be disposable. Some new technology awaits invention or adoption.

Today's iPod could store 20,000 books. That's more than most people would read in a lifetime. But just 10 years from now, an iPod might be able to hold 20 million books—more than are in Harvard University's collection. (If you insist on having the pictures and diagrams in those books, too, perhaps you have to wait until 2017. By then you'll be able to carry around the complete text for all the volumes in the Library of Congress.) To complete this vision, of course, we'll need a lightweight, easy-to-read screen to display text. And we'll need technologies that allow for rapidly digitizing millions of books and other documents, and for extracting text without errors, so the books are searchable.

If we go out a few more years, iPods and similar devices will be able to store massive numbers of movies, rather than the paltry one or two you can carry around today. In fact, 20 years from now, a teenager will probably be able to shuffle down the street with every movie ever made in a $400 iPod. There will be tremendous business opportunities in digitizing old television shows and films, and for developing technologies that will let users browse and search them all. And of course we'll witness epic battles over content ownership and compensation.

But personal storage is only one exponential technology: plenty of others exist. Intel has just announced that it is going to add a second processor to its previously one-processor consumer chips. And chips with even more processors are coming: I know of lab prototype chips with 16 processors. Multiple processors allow many threads of computation to proceed at once, and this changes the paradigm of how to do computing. It requires new approaches in some aspects of programming and other areas of computer science—but it will enable new applications, such as fast, cheap processing of stereo vision.

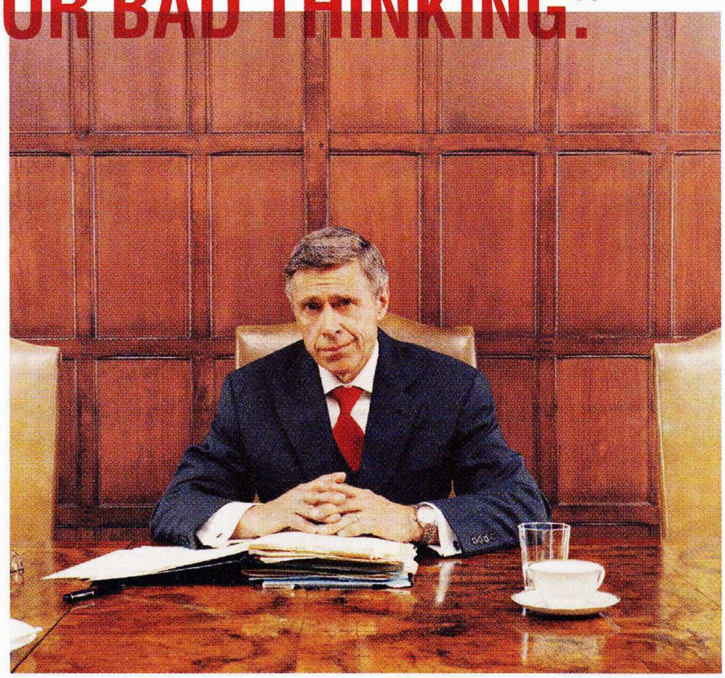
Meanwhile, wireless bandwidth and range are surging. Wireless connections to laptops and desktops have speeded up nearly fivefold in recent years. Over the next five years, we'll see another 20-fold gain. New high-bandwidth networks will have ranges of tens of kilometers, versus today's tens of meters. These trends will let us live always-connected broadband lives and enjoy a range of new services.

Finally, the cost of sequencing DNA is diminishing exponentially. By next year, the cost of sequencing a person's genome is expected to be a mere penny per base pair. Compare that to the $10 it cost in 1990. At that rate, sequencing a person's 3.2 billion base pairs should cost only $32,000 by 2020. As a practical matter, it's only necessary to look at 10 million base pairs to cover all the variations in the human genome. Sequencing this number—in order to determine a person's genetic fingerprint and disease susceptibility—would cost only about one dollar by sometime in the 2020s.

One can find plenty more exponentials out there, from the volume of scientific literature (increasing exponentially for hundreds of years already!), to the number of networked sensors that surround us, to the amount of spam we all receive. They, and others, are all going to have an impact on research and development opportunities, and on our lives. Bring them on! TR

Rodney Brooks is director of MIT's Computer Science and Artificial Intelligence Laboratory.

“INNOVATIVE THINKING? WE DON’T EVEN HAVE TIME FOR BAD THINKING.”



“We got nothing until they slammed into us.”

Sensing and networking technologies were supposed to transform the American way of war. But glitches in Iraq created a battlefield “digital divide,” in which front-line units were perpetually in the dark. **BY DAVID TALBOT** PHOTOGRAPHS BY BRYCE DUFFY

Test of his mettle: Lt. Col. Ernest "Rock" Marcone recalls that during the Iraq War, "I was the intelligence-gathering device for my higher headquarters."

THE LARGEST COUNTERATTACK of the Iraq War unfolded in the early-morning hours of April 3, 2003, near a key Euphrates River bridge about 30 kilometers southwest of Baghdad, code-named Objective Peach. The battle was a fairly conventional fight between tanks and other armored vehicles—almost a throwback to an earlier era of war fighting, especially when viewed against the bloody chaos of the subsequent insurgency. Its scale made it the single biggest test to date of the Pentagon's initial attempts to transform the military into a smaller, smarter, sensor-dependent, networked force.

In theory, the size of the Iraqi attack should have been clear well in advance. U.S. troops were supported by unprecedented technology deployment. During the war, hundreds of aircraft- and satellite-mounted motion sensors, heat detectors, and image and communications eavesdroppers hovered above Iraq. The four armed services coordinated their actions as never before. U.S. commanders in Qatar and Kuwait enjoyed 42 times the bandwidth available to their counterparts in the first Gulf War. High-bandwidth links were set up for intelligence units in the field. A new vehicle-tracking system marked the location of key U.S. fighting units and even allowed text e-mails to reach front-line tanks. This digital firepower convinced many in the Pentagon that the war could be fought with a far smaller force than the one it expected to encounter.

Yet at Objective Peach, Lt. Col. Ernest "Rock" Marcone, a battalion commander with the 69th Armor of the Third Infantry Division, was almost devoid of information about Iraqi strength or position. "I would argue that I was the intelligence-gathering device for my higher headquarters," Marcone says. His unit was at the very tip of the U.S. Army's final lunge north toward Baghdad; the marines advanced on a parallel front. Objective Peach offered a direct approach to the Saddam International Airport (since rechristened Baghdad International Airport). "Next to the fall of Baghdad," says Marcone, "that bridge was the most important piece of terrain in the theater, and no one can tell me what's defending it. Not how many troops, what units, what tanks, anything. There is zero information getting to me. Someone may have known above me, but the information didn't get to me on the ground." Marcone's men were ambushed repeatedly on the approach to the bridge. But the scale of the intelligence deficit was clear after Marcone took the bridge on April 2.

As night fell, the situation grew threatening. Marcone arrayed his battalion in a defensive position on the far side of the bridge and awaited the arrival of bogged-down reinforcements. One communications intercept did reach him: a single Iraqi brigade was moving south from the airport. But Marcone says no sensors, no network, conveyed the far more dangerous reality, which confronted him at 3:00 A.M. April 3. He faced not one brigade but three: between 25 and 30 tanks, plus 70 to 80 armored personnel carriers, artillery, and between 5,000 and 10,000 Iraqi soldiers coming from three directions. This mass of firepower and soldiers attacked a U.S. force of 1,000 soldiers supported by just 30 tanks and 14 Bradley fighting vehicles. The Iraqi deployment was just the kind of conventional, massed force that's easiest to detect. Yet "We got nothing until they slammed into us," Marcone recalls.

Objective Peach was not atypical of dozens of smaller encounters in the war. Portions of a forthcoming, largely classified report on the entire Iraq campaign, under preparation by the Santa Monica, CA, think tank Rand and shared in summary with *Technology Review*, confirm that in this war, one key node fell off the U.S. intelligence network: the front-line troops. "What we uncovered in general in Iraq is, there appeared to be something I refer to as a 'digital divide,'" says Walter Perry, a senior researcher at Rand's Arlington, VA, office and a former army signals officer in Vietnam. "At the division level or above, the view of the battle space was adequate to their needs. They were getting good feeds from the sensors," Perry says. But among front-line army commanders like Marcone—as well as his counterparts in the U.S. Marines—"Everybody said the same thing. It was a universal comment: 'We had terrible situational awareness,'" he adds. The same verdict was delivered after the first Gulf War's ground battle, but experts had hoped the more robust technology used in the 2003 conflict would solve the problem.

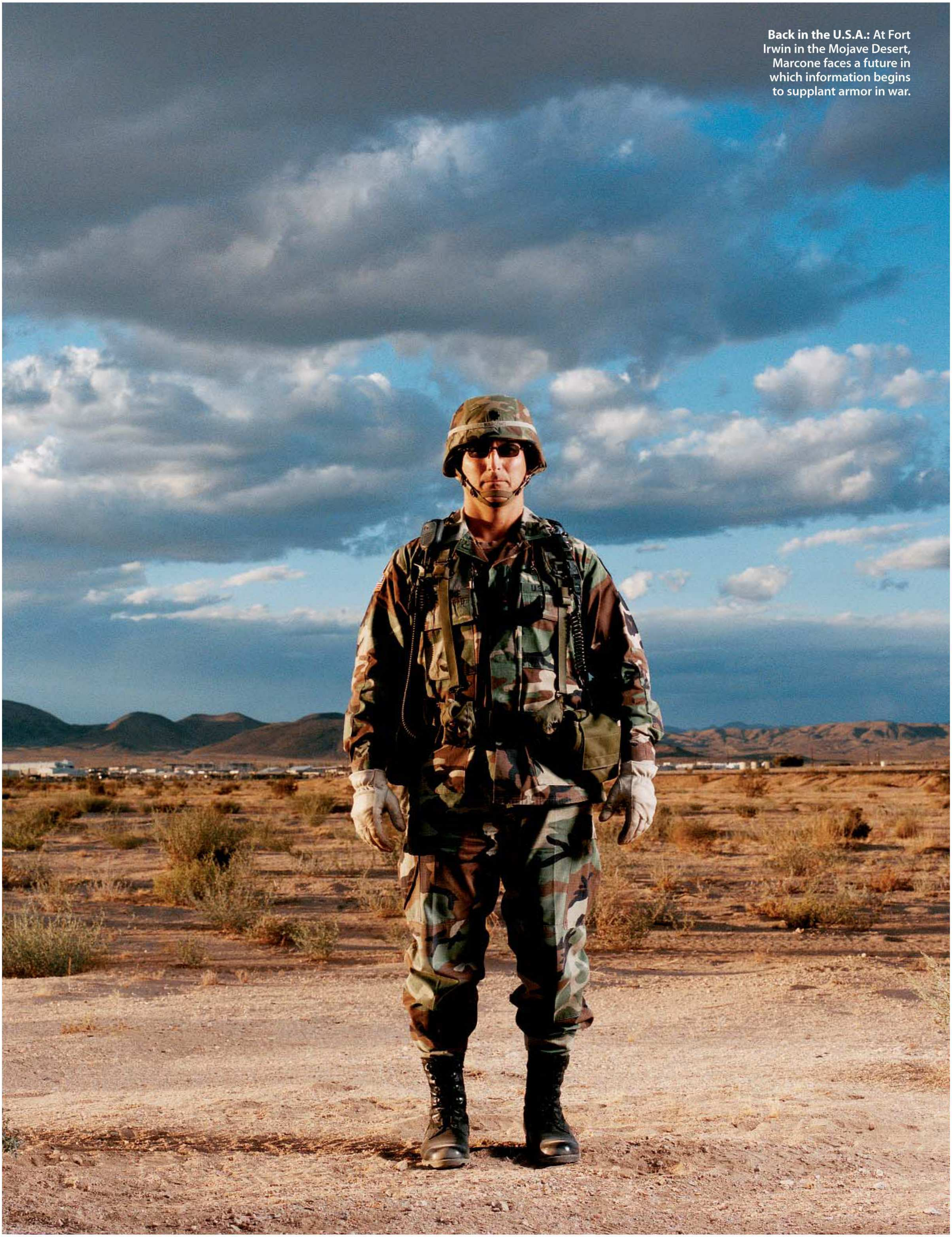
The Pentagon points to the Iraq War's many networking successes. During the blinding sandstorm that lasted from March 25 to 28, 2003, a U.S. radar plane detected an Iraqi Republican Guard unit maneuvering near U.S. troops. Bombers moved in to attack using satellite-guided bombs that were unaffected by poor visibility. And the vehicle-tracking system (known as Blue Force Tracker) successfully ensured that commanders knew the locations of friendly units. Overall, command headquarters in Qatar and Kuwait sported "truly a very impressive digital connectivity" that "had many of the characteristics of future network warfare that we want," Brig. Gen. Robert Cone, then director of the Pentagon's Joint Center for Operational Analysis and Lessons Learned, said in a Pentagon briefing last year.

Yet connectivity in Qatar was matched by a data dearth in the Iraqi desert. It was a problem all the ground forces suffered. Some units outran the range of high-bandwidth communications relays. Downloads took hours. Software locked up. And the enemy was sometimes difficult to see in the first place. As the marines' own "lessons learned" report puts it, "The [First Marine] Division found the enemy by running into them, much as forces have done since the beginning of warfare." Describing the army's battle at Objective Peach, John Gordon, another senior researcher at Rand and also a retired army officer, put it this way: "That's the way it was done in 1944."

The Pentagon maintains that the Iraq War had impressive digital connectivity and many characteristics of networked warfare.

INFORMATION IS ARMOR

Military intellectuals call them "revolutions in military affairs." Every few decades, a new technology or a new "doctrine," to use



Back in the U.S.A.: At Fort Irwin in the Mojave Desert, Marcone faces a future in which information begins to supplant armor in war.

the military jargon, changes the nature of war. Single technologies, like gunpowder or nuclear weapons, spur some of these revolutions. New doctrines, like Napoleonic staff organization or Nazi blitz tactics, drive others. And some are the result of many simultaneous advances, like the airplanes, chemical weapons, and machine guns of World War I—which achieved new rates of slaughter.

The newest revolution is known to Pentagon planners as "force transformation." The idea is that robotic planes and ground vehicles, empowered by an ever expanding range of sensing, targeting, imaging, and communications capabilities (new technologies), would support teams of networked soldiers (a new doctrine). According to its most expansive definition, force transformation is intended to solve the problem of "asymmetric warfare" in the 21st century, where U.S. forces are not directly confronted by conventional militaries but rather must quell insurgencies, destroy terrorist cells, or mitigate regional instability. Among other things, more nimble, networked forces could employ tactics like "swarming"—precise, coordinated strikes from many directions at once.

Perversely, U.S. units were sometimes attacked when they stopped their vehicles to accept downloads on enemy positions.

The technologies driving force transformation are incredibly complicated. It will take at least 31 million lines of computer code to run something called Future Combat Systems, the centerpiece of the Pentagon's transformation effort. An army-run program expected to cost more than $100 billion, it consists of a suite of new manned and unmanned machines, all loaded with the latest sensors, roaming the air and ground. Software will process sensor data, identify friend and foe, set targets, issue alerts, coordinate actions, and guide decisions. New kinds of wireless communications devices—controlled by yet more software and relaying communications via satellites—will allow seamless links between units. Currently, 23 partner companies, many with their own platoons of subcontractors, are building the systems; Boeing of Chicago and Science Applications International of San Diego are charged with tying them all together and crafting a "system of systems" by 2014.

In this grand vision, information isn't merely power. It's armor, too. Tanks weighing 64 metric tons could be largely phased out, giving way to lightly armored vehicles—at first, the new 17-metric-ton Stryker troop carrier—that can avoid heavy enemy fire if need be. These lighter vehicles could ride to war inside cargo planes; today, transporting large numbers of the heaviest tanks requires weeks of transport via land and sea. "The basic notion behind military transformation is that information technologies allow you to substitute information for mass. If you buy into that, the whole force structure changes," says Stuart Johnson, a research professor at the Center for Technology and National Security Policy at National Defense University in Washington, DC. "But the vision of all this is totally dependent on information technologies and the network. If that part of the equation breaks down, what you have are small, less capable battle platforms that are more vulnerable."

The Iraq War represented something of a midpoint—and an early proving ground—in the move toward this networked force. The U.S. offensive did include the old heavy armor, and it didn't sport all the techno-goodies envisioned by the promoters of force transformation. But it did presume that satellite- and aircraft-mounted sensors would support the fighting units on the ground. The war's backbone was a land invasion from Kuwait. Ultimately, some 10,000 vehicles and 300,000 coalition troops rumbled across the sandy berm at the Kuwaiti border, 500 kilometers from Baghdad. Desert highways crawled with columns of Abrams tanks, Bradley fighting vehicles, armored personnel carriers, tank haulers, Humvees, and of course, fuel tankers to slake the fleet's nine-million-liter daily demand for fuel.

Several communications links were designed to connect these vehicles with each other and with commanders. First, and most successfully, at least 2,500 vehicles were tracked via Blue Force Tracker: each vehicle broadcast its Global Positioning System coordinates and an ID code. This thin but critical stream of data was in essence a military version of OnStar. Commanders in Qatar saw its content displayed on a large plasma screen. Marcone, like some other commanders in the field, also had access to it, thanks to a last-minute installation in his tank before the invasion.

"A CRITICAL VULNERABILITY"

Once the invasion began, breakdowns quickly became the norm. For the movement of lots of data—such as satellite or spy-plane images—between high-level commanders and units in the field, the military employed a microwave-based communications system originally envisioned for war in Europe. This system relied on antenna relays carried by certain units in the advancing convoy. Critically, these relays—sometimes called "Ma Bell for the army"—needed to be stationary to function. Units had to be within a line of sight to pass information to one another. But in practice, the convoys were moving too fast, and too far, for the system to work. Perversely, in three cases, U.S. vehicles were actually attacked while they stopped to receive intelligence data on enemy positions. "A lot of the guys said, 'Enough of this shit,' and turned it off," says Perry, flicking his wrist as if clicking off a radio. "'We can't afford to wait for this.'"

One Third Infantry Division brigade intelligence officer reported to Rand that when his unit moved, its communications links would fail, except for the GPS tracking system. The unit would travel for a few hours, stop, hoist up the antenna, log back onto the intelligence network, and attempt to download whatever information it could. But bandwidth and software problems caused its computer system to lock up for ten to 12 hours at a time, rendering it useless.

Meanwhile, commanders in Qatar and Kuwait had their own problems. Their connectivity was good—too good. They received so much data from some of their airborne sensors that they couldn't process it all; at some points, they had to stop accepting feeds. When they tried to send information to the front, of course, they found the line-of-sight microwave-relay system virtually disabled. At the command levels above Marcone's—the

Dashboard duty: Hastily installed in Kuwait, computer screens in tanks and other vehicles successfully showed the positions of "friendly" units as blue icons.

brigade and even the division levels—such problems were ubiquitous. "The network we had built to pass imagery, et cetera, didn't support us. It just didn't work," says Col. Peter Bayer, then the division's operations officer, who was south of Marcone's battalion on the night of April 2 and 3. "The link for V Corps [the army command] to the division, the majority of time, didn't work, to pass a digital image of something."

Sometimes, intelligence was passed along verbally, over FM radio. But at other times vehicles outran even their radio connections. This left just one means of communication: e-mail. (In addition to tracking vehicles, Blue Force Tracker, somewhat quaintly, enabled text-only e-mail.) At times, the e-mail system was used for issuing basic orders to units that were otherwise out of contact. "It was intended as a supplement, but it wound up as the primary method of control," says Owen Cote, associate director of the Security Studies Program at MIT. "The units did outrun their main lines of communications and networking with each other and with higher command. But there was this very

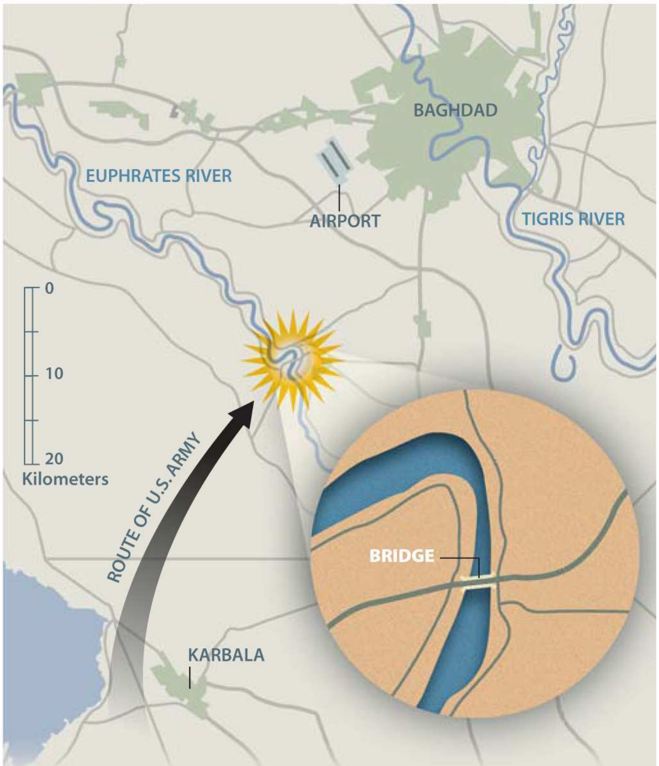
thin pipe of information via satellite communications that allowed the high command to see where units were."

The network wasn't much better for the marines pushing forward on a separate front. Indeed, the marines' lessons-learned report says that First Marine Division commanders were unable to download crucial new aerial reconnaissance photographs as they approached cities and towns. High-level commanders had them, but the system for moving them into the field broke down. This created "a critical vulnerability during combat operations," the report says. "There were issues with bandwidth, exploitation, and processes that caused this state of affairs, but the bottom line was no [access to fresh spy photographs] during the entire war."

Fortunately for U.S. forces, they faced little resistance during the Iraq War. The Iraqis launched no air attacks or Scud missiles. Iraqi soldiers shed uniforms and boots and walked away barefoot, studiously avoiding eye contact with the Americans. When they did fight, they used inferior weapons and vehicles. To be sure, U.S. units racing forward would run into stiff "meeting engagements"—jargon for a surprise collision with enemy forces. But such meetings would end quickly. "They [the U.S. forces] would succeed in these meeting engagements," Cote says. "But we were far from the vision of total knowledge. You can easily see how we would have paid a big price if it were a more robust opponent."

The problems are acknowledged at high levels. However, Art Cebrowski, retired vice admiral and director of the Pentagon's Office of Force Transformation, cites "existence proofs" that networking was generally successful in Iraq. In previous conflicts, combat pilots were briefed on targets before takeoff; hours would elapse between target identification and an actual attack. In the Iraq War, more than half of aerial sorties began without targets in mind, Cebrowski says. Instead, targets were identified on the fly and communicated to the airborne pilots. "Combat was moving too fast; opportunities were too fleeting. You had to be in the networked environment" for it to work, says Cebrowski.

Clearly, networking during the ground war was not as successful. "There were certainly cases where people didn't have the information they needed. This was a very large operation, so you would expect to see the good, the bad, and the ugly in it," Cebrowski acknowledges. But it would be a mistake to use these problems as an argument against phasing out heavy armor, he says. Big tanks require not only considerable time and energy to move into battle but also larger supply convoys that are themselves susceptible to attack. According to Cebrowski, by keeping heavily armored tanks your main line of defense, "you simply move your vulnerability to another place on the supply chain."



Battle at Objective Peach

On April 2, 2003, army lieutenant colonel Ernest "Rock" Marcone led an armored battalion with about 1,000 U.S. troops to seize "Objective Peach" *(inset)*, a bridge across the Euphrates River, the last natural barrier before Baghdad. That night, the battalion was surprised by the largest counterattack of the war. Sensing and communications technologies failed to warn of the attack's vast scale—between 5,000 and 10,000 Iraqi troops and about 100 tanks or other vehicles. The U.S. success in the battle was the result of superior tactics and equipment.

SW INFOGRAPHIC

ALPHA GEEKS AT WAR

Some defenders of force transformation argue that the troops' problems were doctrinal, not technological. According to this line of reasoning, the networking of the Iraq War was incomplete—because it was fatally grafted onto old-fashioned command and control systems. Sensor information went up the chain of command. Commanders interpreted it and made decisions. Then they passed commands, and tried to pass relevant data, down the chain. The result: time delays and the magnification of individual communications failures.

Better, some say, that information and decision-making should flow horizontally. In fact, that's how the 2001 war in Afghanistan was fought. Special-operations forces organized into "A teams" numbering no more than two dozen soldiers roamed the chilly mountains near the Pakistan border on horseback, rooting out Taliban forces and seeking al-Qaeda leaders. The teams and individuals were all linked to one another. No one person was in tactical command.

But despite the lack of generals making key decisions, each of these teams of networked soldiers had a key node, an animal once confined to corporate IT departments: the alpha geek, who managed the flow of information between his team and the others. The U.S. special forces also maintained a tactical Web page, collating all the information the teams collected. And this page was managed by a webmaster in the field: the metageek of all alpha geeks.

How did the page perform? Postmortems and reports on special-forces operations in Afghanistan are more secret than those from the Iraq War. A report on one major special-forces operation, Operation Anaconda—an attempt to encircle and root out al-Qaeda in March 2002—is due soon from National Defense Uni-

versity. Still, anecdotes are trickling out of the special-forces community. And they provide a startlingly different view of warfare than Marcone's tank-level vantage. One account, not previously reported, comes from John Arquilla, an expert in unconventional warfare at the Naval Postgraduate School in Monterey, CA.

The scene was a cold night in the late fall of 2001. In New York City, the World Trade Center ruins were still smoldering. In Afghanistan, a U.S. Air Force pilot en route from Uzbekistan noticed flashing lights in the mountains below, near the Pakistan border. Suspecting that the flashes might be reflections from hooded headlights of trucks bumping along, he radioed his observation to the webmaster. The webmaster relayed the

"If there is this 'revolution in military affairs,'...we are still just scratching the surface of it....It's a pretty patchy performance."

message across a secure network accessible to special forces in the region. One team replied that it was near the position and would investigate. The team identified a convoy of trucks carrying Taliban fighters and got on the radio to ask if any bombers were in range. One U.S. Navy plane was not far off. Within minutes, the plane bombed the front and rear of the convoy, sealing off the possibility of escape. Not long after, a gunship arrived and destroyed the crippled Taliban column.

The episode, as recounted by Arquilla, shows what's possible. "That's networking. That's military transformation right there," Arquilla says. "Some of the problems in Iraq grew out of an attempt to take this cascade of information provided by advanced information technology and try and jam it through the existing stovepipes of the hierarchical structure, whereas in Afghanistan we had a more fluid approach. This is war by minutes, and networking technology allows us to wage war by minutes with a great probability of success." In this case, service members on the battlefield collected data, shared that data, made decisions, and ordered strikes.

NETWORK VS. INSURGENTS?

Perhaps Pentagon optimists are right. Perhaps the success of Blue Force Tracker, of the special-forces assault on the Taliban column, and of air force operations in Iraq accurately foretell the full digital transformation of war. But to many observers, the disruption of communications between the main ground combat units in Iraq was not a very promising sign at all. "If there is this 'revolution in military affairs,' and if this revolution is based on technologies that allow you to network sensors and process information more quickly and spread it out quickly in digestible form, we are still just scratching the surface of it," says Cote of MIT. "If you look at the performance of a lot of the components of the first efforts in that direction, it's a pretty patchy performance." And then there's the question of terror and insurgency. Even if the Pentagon transforms war fighting, the meaning of the word "war" is itself undergoing a transformation. More Americans died in the September 11 attacks than have subsequently died in Afghanistan and Iraq. And the Iraq insurgency challenges the meaning of the Iraq military victory. Future wars will be fought in urban zones by low-tech fanatics who do not follow the old rules. They are unlikely to array themselves as convenient targets for the U.S. to detect and destroy. Indeed, a leading cause of death among U.S. soldiers in Iraq today is improvised bombs targeting passing vehicles such as Humvees.

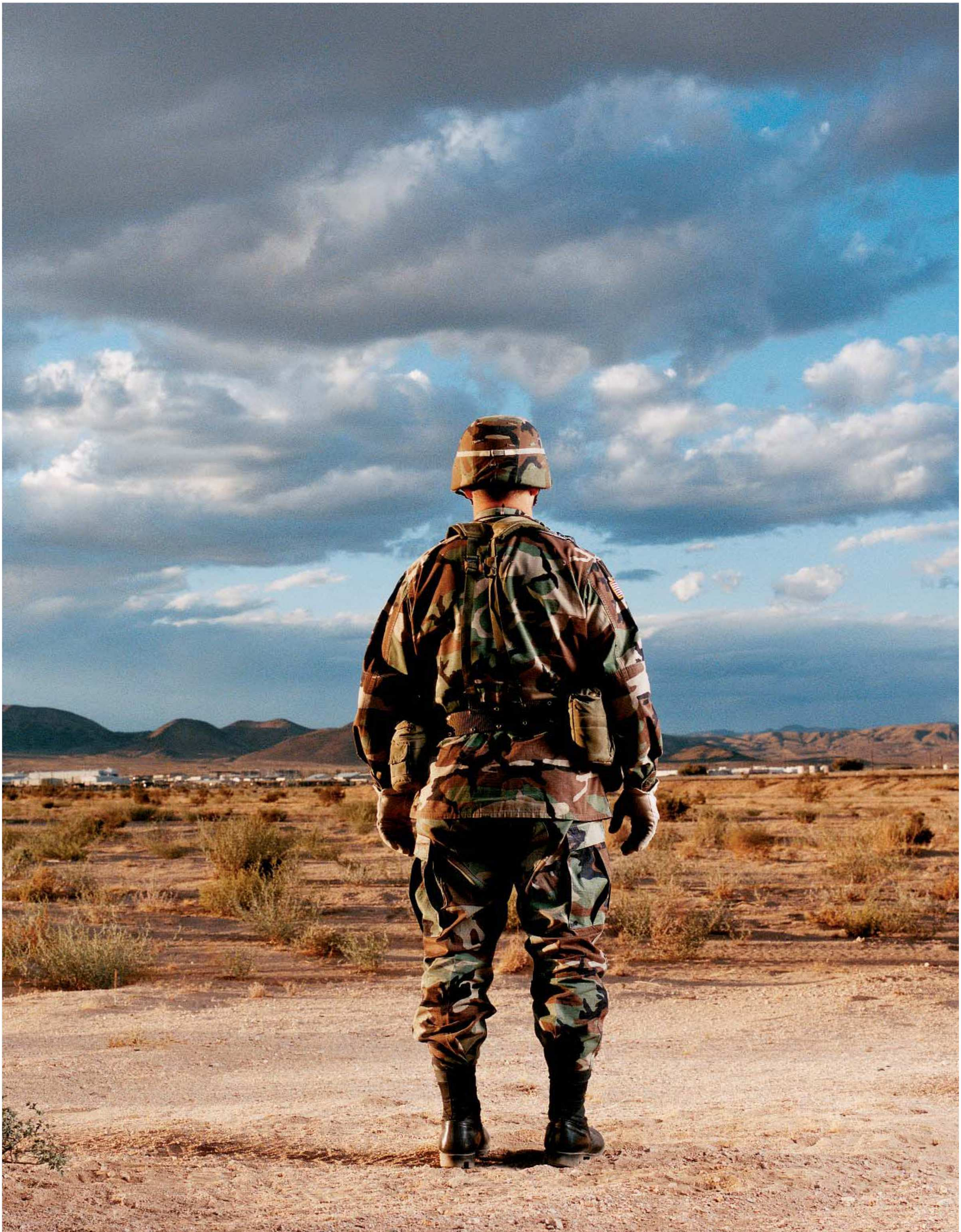
Arquilla says some networking technology can be—and is being—brought to bear against the Iraq insurgency. While actual strategies are secret, some general tactics are known. Suspicious vehicles can be tracked, and their connections to other people and locations determined. Small drone aircraft can deliver video feeds from urban buildings as well as from desert battlefields. Sensors can help find a sniper by measuring the acoustical signature of a bullet. And jamming devices can sometimes block radio-controlled detonation of roadside bombs. But old-fashioned tips from humans are likely to trump technology. "Our networks don't really have the sensitivity to keep up with unconventional enemies. All the network does is move information around, but the information itself is the key to victory," says Loren Thompson, chief operating officer of the Lexington Institute, a think tank in Arlington, VA. "It's a little hard to derive meaningful lessons from networked war fighting when you are dealing with such modest threats."

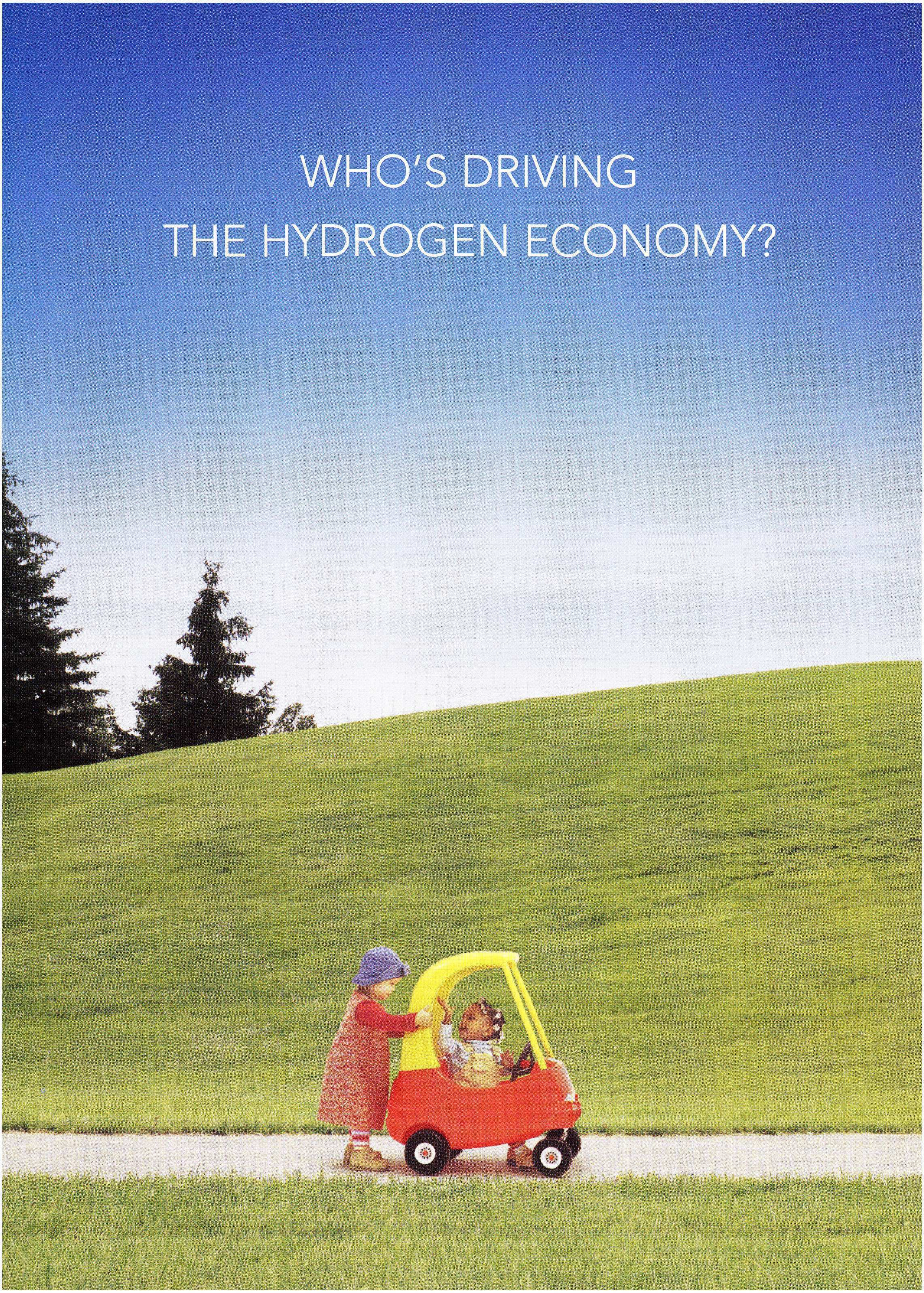
The welter of postmortems from the Iraq and Afghanistan wars tell many stories. But one thing is clear: Marcone never knew what was coming at Objective Peach. Advanced sensors and communications—elements of future networked warfare designed for difficult, unconventional battles—failed to tell him about a very conventional massed attack. "It is my belief that the Iraqi Republican Guard did nothing special to conceal their intentions or their movements. They attacked en masse using tactics that are more recognizable with the Soviet army of World War II," Marcone says.

And so at a critical juncture in space (a key Euphrates bridge) and time (the morning of the day U.S. forces captured the Baghdad airport), Marcone only learned what he was facing when the shooting began. In the early-morning hours of April 3, it was old-fashioned training, better firepower, superior equipment, air support, and enemy incompetence that led to a lopsided victory for the U.S. troops. "When the sun came up that morning, the sight of the cost in human life the Iraqis paid for that assault, and burning vehicles, was something I will never forget," Marcone says. "It was a gruesome sight. You look down the road that led to Baghdad, for a mile, mile and a half, you couldn't walk without stepping on a body part."

Yet just eight U.S. soldiers were wounded, none seriously, during the bridge fighting. Whereas U.S. tanks could withstand a direct hit from Iraqi shells, Iraqi vehicles would "go up like a Roman candle" when struck by U.S. shells, Marcone says. Sitting in an office at Rand, Gordon puts things bluntly: "If the army had had Strykers at the front of the column, lots of guys would have been killed." At Objective Peach, what protected Marcone's men wasn't information armor, but armor itself. TR

David Talbot is a *TR* senior editor.




WHO'S DRIVING
THE HYDROGEN ECONOMY?

Jet set: In Alan Epstein's lab is a collection of jet engines, including the type used to power a Boeing 737.

POWER ON A CHIP

TINY GAS TURBINE ENGINES COULD SOON POWER HANDHELD ELECTRONIC DEVICES—AND FINALLY MAKE BATTERIES OBSOLETE.

BY DAVID H. FREEDMAN

PHOTOGRAPHS BY KATHLEEN DOOHER

ALAN EPSTEIN IS QUICK TO TELL YOU HE'S A "JET ENGINE GUY"—

just in case you haven't guessed as much from the turbine engine parts strewn around his office or the museum on his lab's ground floor, which includes a rare example of a 1944 German engine that helped kick off the jet age. For the director of MIT's Gas Turbine Laboratory, who stands a slightly stooped five foot six, the fascination has to do with raw power. "The engines on a Boeing 747 shove air through at Mach 1 with 120,000 pounds of force," says Epstein. "The engines on three 747s put out as much power as a nuclear power plant."

Gas turbines powered much of 20th-century technology, from commercial and military aircraft to the large gas-fired plants that helped supply U.S. electricity. But these days it isn't the hulking machines in the lab's museum that capture Epstein's enthusiasm. Instead it's a jet engine shrunk to about the size of a coat button that sits on the corner of his desk. It's a Lilliputian version of the multiton jet engines that changed air travel, and, he believes, it could be key to powering 21st-century technology.

Though the turbine's blades span an area smaller than a dime, they spin at more than a million revolutions per minute and are designed to produce enough electricity to power handheld electronics. In the foreseeable future, Epstein expects, his tiny turbines will serve as a battery replacement, first for soldiers and then for consumers. But he has an even more ambitious vision: that small clusters of the engines could serve as home generating plants, freeing consumers from the power grid, with its occasional black- and brownouts. The technology could be especially useful in poor countries and remote areas that lack extensive and reliable grids for distributing electricity. A comparison to how the continuous shrinkage of the integrated circuit drove the microelectronic revolution is tempting. "Just as PCs pushed the computing infrastructure out to users, microengines could push the energy infrastructure of society out to users," says Epstein.

Epstein's immediate goal, however, is to use these miniature engines as a cheap and efficient alternative to batteries for cell phones, digital cameras, PDAs, laptop computers, and other portable electronic devices. The motivation is simple: batteries are heavy and expensive and require frequent recharging. And they don't produce much electricity, for all their size and weight.

The consequences of these failings go beyond consumer inconvenience. Today's soldiers are often forced to lug around brick-sized batteries to power their high-tech gear. And hamstrung by short-lived power supplies, designers of next-generation electronics are frequently forced to leave out energy-hungry improvements and features like bigger, brighter screens and more powerful processors. Take, for example, the "ultimate PDA" from Frog Design, a Sunnyvale, CA–based firm specializing in industrial design. The device combines multiple cell-phone and Wi-Fi radio protocols, GPS location, a projection screen, the functionality of a laptop, and the ability to browse through video libraries and play full-length movies. But it exists only as a mock-up; it would drain any reasonably sized battery in half an hour. With functions like GPS location and radio communications, "you're just eating through batteries," says Valerie Casey at Frog Design.

A micro gas turbine engine would change all that. It could run for ten or more hours on a container of diesel fuel slightly larger than a D battery; when the fuel cartridge ran out, a new one could be easily swapped in. Each disposable cartridge would pack as much energy as a few heavy handfuls of lithium-ion batteries. As a result, a small pack of the cheap and light cartridges could power a PDA or cell phone through several days of heavy usage, no wall-outlet recharging required—a highly attractive feature for soldiers in remote locations or travelers. What's more, the miniature turbine takes up about a quarter of the volume of a typical cell-phone battery.

Not that a micro engine is without drawbacks. It would shoot a tiny stream of hot exhaust gas, for one thing, making it more suitable for devices clipped to belts or carried in briefcases than for those stuffed in pockets. The engine itself would get hot, though an exhaust suppressor would easily keep devices from getting much warmer than they do today. But for many energy-hungry applications, says Epstein, a tiny turbine's remarkable power output would far outweigh any disadvantages. Suggests Epstein, "You don't need a very good jet engine to do better than batteries."

GROUNDED

Epstein started thinking about building a jet engine on a chip nearly a decade ago. At the time, microelectromechanical systems (MEMS) were picking up speed. Techniques had emerged for carving new types of features into the surfaces of slabs of silicon, including sealed chambers and pipes and moving parts like spinning wheels—most of the parts needed for a gas turbine engine. Less clear at first was what one would do with a miniature fuel-burning engine. "We thought we'd be able to get the cost way down if we could figure out a reason for needing a lot of them," says Epstein. "But the only thing we could see doing with tiny engines was flying tiny airplanes, and that seemed stupid. Of course, we hadn't counted on the DoD."

Sure enough, the U.S. military was suddenly gung ho over the idea of 15-centimeter-long planes that could carry small cameras for surveillance. The engineers at Epstein's lab were somewhat less enthusiastic; they suspected that getting jet chips that were airworthy would take a couple of decades. Then Epstein latched onto a more immediate military need: freeing soldiers from the batteries that many of them have to lug around to power radios, GPS receivers, night-vision goggles, and other gadgets. And unlike a miniature aircraft engine, a battery-replacing jet chip would have enormous commercial potential.

Other materials scientists and engineers were already beginning to work on ways to shrink power-producing machines to supplement or replace batteries, creating a new field called "power MEMS." The most popular approach involved shrinking fuel cells, which typically pass hydrogen through a membrane

Tiny turbine: Epstein holds a nonfunctional prototype of a gas turbine engine. A working version is due out soon.

that pulls electrons out to create an electric current. But Epstein was convinced gas turbines were a better way to go, because of their unmatched ability to wring power out of hydrocarbon fuels. The technology becomes even more appealing where minimizing weight and volume is critical, as with portable devices. A jet chip would be at most half the size of a micro fuel cell of equal energy capacity. A gas turbine should also be relatively easy to fabricate, figured Epstein, because it could be built entirely out of silicon, using standard fabrication techniques.

Though Epstein envisioned his micro version working roughly the same way a conventional gas turbine does, much about micro jet engines was a mystery. Would silicon crumble under 1,300 °C temperatures? Could microscopic bearings handle a million-plus revolutions per minute? With funding from the U.S. military, Epstein tapped into the expertise of neighboring MIT labs in fluid mechanics, materials science, structural engineering, and microfabrication. The project team eventually swelled to dozens of researchers, including Mark Spearing, a materials engineer charged with finding ways to keep the silicon microstructures intact under furious heat and pressure. "Most MEMS chips involve etching small structures up to 10 microns tall," says Spearing. "We were going to parts that are hundreds of microns tall."

IN HAND

Earlier this year, Epstein and his coworkers finished making engines in which each of the individual parts functions: the combustion chamber burns fuel, and the turbine blades spin. The resulting device is sealed all around, with holes on the top and bottom for air intake, fuel intake and exhaust. One shortcoming: it doesn't run continuously. The obstacle, says Epstein, is imperfections that imbalance the blades and cause them to wobble. "We think we know what to do to correct it," he says. "The problem is that it takes three months to get new parts when you make an adjustment, so we're just waiting for the new parts." Epstein predicts the chip will be functioning within months—a little ahead of schedule. Spearing estimates a version capable of putting out enough power to run devices would take two to three years more, with another year or two beyond that to produce a marketable version.

Power hungry: Epstein believes tiny versions of gas turbines could provide plenty of power for handheld devices.

That means conceding an early lead in the power MEMS race to fuel cells, which are already hitting the market. Albany, NY–based MTI Micro Fuel Cells is preparing to launch one the size of a deck of cards for use in handheld industrial devices such as radio-frequency ID-tag readers and has plans to roll out a slightly smaller version for cell phones, PDAs, and digital cameras. Medis Technologies of New York City intends to sell a $20 disposable micro fuel cell next year.

"Our competition is fuel cells, absolutely," says Epstein. But he insists that turbine chips can make up any lost ground. "Up to now a few million dollars has been invested in microturbines, compared to the billions invested in fuel cells," he points out. Epstein's faith is fueled by the inherent advantages he sees in turbines. Even micro fuel cells are larger, and they're much more finicky about fuel than a turbine engine. But in the end, it all comes down to power. Most micro fuel cells struggle to put out a watt or two, while Epstein's prototypes could provide 15 to 20 watts, more than enough to keep a power-hungry handheld device going. Laptop computers can require 50 watts, but a few turbines working together could easily pump that much power out. Likewise, Epstein envisions that a cluster of tiny engines, each capable of producing up to a hundred watts, could supply a home with an efficient and reliable source of electricity.

That switchover will surely take time. But Epstein sees it as the natural extension of the remarkable progress jet engines have made throughout the second half of the 20th century, from the novel fighter planes that appeared in World War II to the behemoth engines that power today's jumbo jets. And though Epstein predicts that, from an engineer's point of view, his tiny chip-based turbines will initially perform more like the pioneering jets of the 1940s than like today's superefficient gas turbines, he is fully confident in the technology's vast potential to evolve. Indeed, the aging engines in his lab's museum are an ever present reminder of the gas turbine's awesome power. TR

David H. Freedman is a freelance writer based in the Boston area.

NEW

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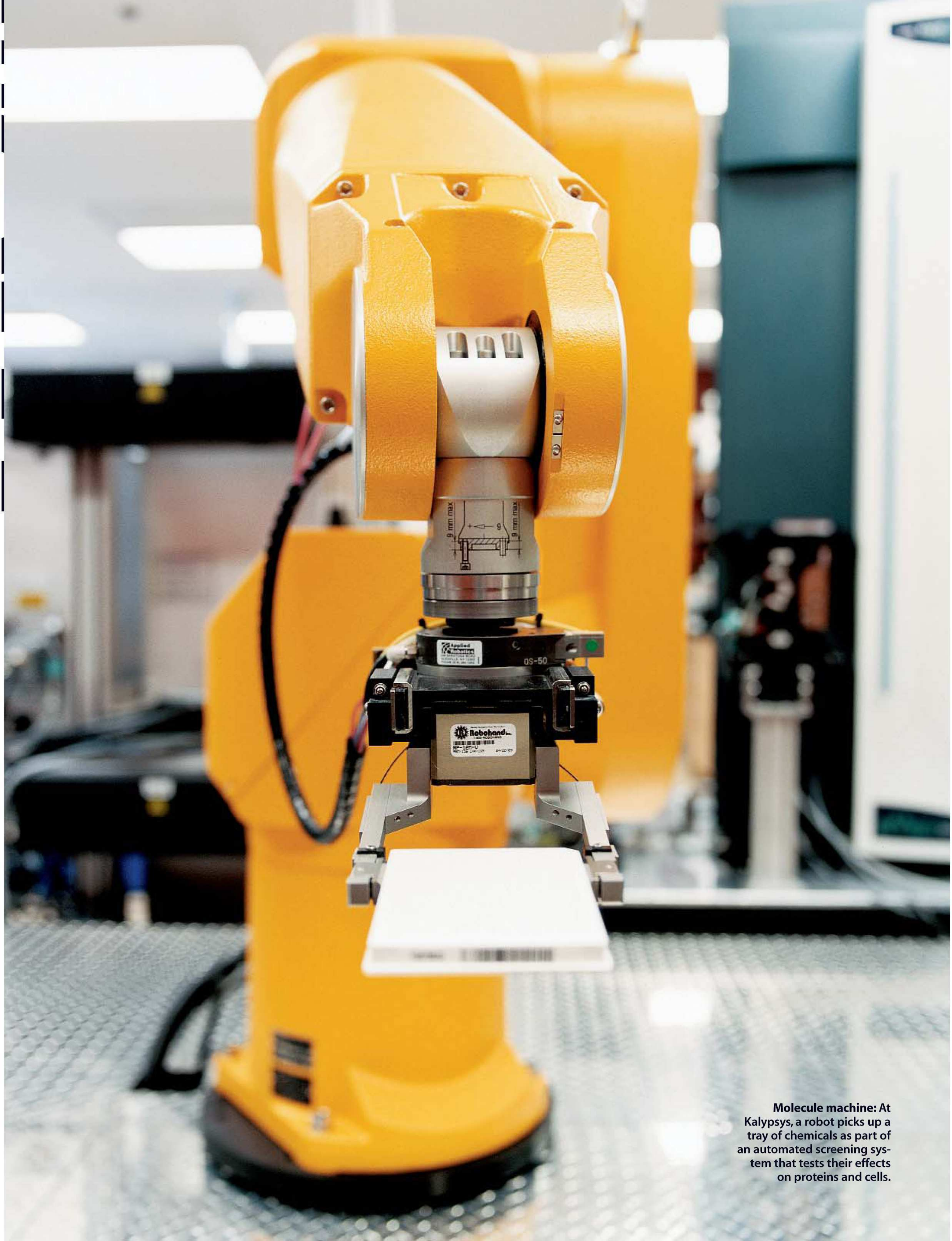
BY GREGORY T. HUANG PHOTOGRAPH BY DAVE LAURIDSEN

IT HAS BEEN THE MANTRA of genomics researchers for nearly 20 years now: understanding the genome will yield better and more affordable drugs that will cure even the deadliest diseases. But in the thick of this much ballyhooed genomic revolution, newcomers to the pharmacy shelf are few and far between and seem to offer (with a handful of notable exceptions) only trivially new ways to lower cholesterol and boost sex lives. Why? After all, researchers have in hand a draft of the human genome, the parts list for the hundreds of thousands of proteins that carry out the body's biological business. And they have already discerned that hundreds of those proteins—ones that go awry in cancer, for instance—would make obvious targets for new drugs. ■ The problem is that there's a yawning gap between traditional pharmaceutical companies and genomics research. Genomics, still largely an academic pursuit, might divulge a specific protein's role in cell division, say, and what chemical probe blocks the protein's action. That may be important for understanding how tumors grow, but it is years away from where the pharmaceutical industry would begin developing a new cancer drug. In practice, most companies avoid novel targets because they are unproven, tied to unwanted effects downstream, or just too hard to hit with familiar drug compounds. The result: a no man's land of unpursued protein targets, half-baked chemical probes, and what-might-have-been drugs.



Molecule machine: At Kalypsys, a robot picks up a tray of chemicals as part of an automated screening system that tests their effects on proteins and cells.

Drug tester: John McKearn, president of Kalypsys, in front of a library of potential drug candidates.

"IF WE CAN POPULATE THE SCIENTIFIC LITERATURE WITH DATA ON SMALL MOLECULES, THAT COULD SET OFF LIGHT BULBS TOWARDS THERAPIES THAT WOULDN'T OTHERWISE HAPPEN."—FRANCIS COLLINS

What could help bridge this gap is the emerging science of chemical genomics, which uses vast libraries of "small molecules"—synthetic compounds that bind to proteins and alter their functions—to probe how all the proteins encoded by the genome work in concert. Small molecules, it turns out, are a big deal for drug companies, too. From 1980 to 2003, 90 percent of new drugs approved by the U.S. Food and Drug Administration were made from small molecules. From aspirin to allergy pills, most small-molecule drugs are cheap and easy to produce—in stark contrast to the protein-based and other "large molecule" drugs on which biotech companies tend to place their bets. Combining the convenience of small-molecule drugs with the intelligence of genomic science could revitalize the lumbering drug industry and greatly improve health care.

LIBRARY SCIENCE

For Christopher Austin at Merck, it began with a simple question: "Chris, how would you like to come help us figure out what to do with the genome?" The proposition came from Francis Collins, who as director of the National Human Genome Research Institute at the National Institutes of Health (NIH) had led the effort to complete the Human Genome Project. It was mid-2002.

Austin, then director of genomic neuroscience at Merck Research Laboratories, jumped at the opportunity. This would be a chance to take a leading role in translating genomic research and new drug targets into novel, more effective therapies. "The genome presents an enormous problem, if you're a pharmaceutical company," Austin explains. "The failure rate is higher if you take on unprecedented targets." That's why drug companies tend to focus on a narrow set of targets and compounds they already understand.

In an effort to broaden the playing field, NIH announced in June that it is opening a Chemical Genomics Center. Headed by Austin, the center is part of a four-year "molecular libraries" initiative whose $32 million annual budget is expected to grow to about $100 million. The plan: to fund a nationwide network of centers to screen small molecules for their effects on cells and proteins and aggregate the results in a public database. "If we can populate the scientific literature with data on small molecules," Collins says, "that could set off light bulbs towards therapies that wouldn't otherwise happen."

Until now, most academics have not had access to the industrial-strength technologies required to synthesize and screen small molecules. And drug companies don't share data on their compounds. The hope is that, with this effort, academics will systematically explore small molecules, and drug companies will use the public results to better fight cancer, diabetes, and rare diseases that they currently have little financial incentive to pursue.

To jump-start the initiative, Collins and Austin signed a deal worth up to $30 million to license a molecular-screening system from Kalypsys, a San Diego, CA, startup. The system represents the state of the art in combinatorial chemistry for making small molecules, the hardware for screening them, and the informatics software for analyzing the results. More broadly, it represents an important step in turning the science of chemical genomics into practical technology that companies and research groups can use. "In terms of technology development," says Austin, "we are about where the Human Genome Project was in 1988"—two years after the invention of the automated DNA sequencer. But chemical genomics is vastly more complicated, he says. "This will make DNA sequencing look like child's play."

THROUGH THE SCREEN DOOR

Sitting in the Kalypsys boardroom, dressed all in black despite the summer weather, John McKearn says he used to be a serial killer—of drug candidates. The company's president and chief scientific officer is talking about the problem he saw during his stint at Pharmacia, the Peapack, NJ, pharmaceutical company acquired by drug giant Pfizer in 2003. According to McKearn, companies test thousands of candidates in series, wasting precious time and money on one compound only to find that it fails in some respect and then moving on to test another. To survive, McKearn says, drug companies must learn to screen compounds in parallel and to kill, or reject, the unpromising ones as early as possible. That's what Kalypsys aims to do.

The bottom line: McKearn predicts that Kalypsys's technology can shave 50 percent off the time and cost of traditional drug development. Considering that drug companies average $800 million in R&D investment for each compound that receives FDA approval, that's no idle boast. McKearn points out that Kalypsys took only six months to discover new anti-inflammatory drug candidates in animals—a process he says would take most drug companies two to three years—and plans to seek the FDA's permission to test its first drug on people in 2005. But of course, "the proof of the pudding is in the eating," says Janice Reichert, senior research fellow at the Tufts Center for the Study of Drug Development. "They have a good system, but it's not revolutionary."

Not yet, at least. Indeed, translating the latest biology into new small-molecule drugs has universally proven difficult. "Pharma [the pharmaceutical industry] is unprepared for the post-genomic age," McKearn says. The numbers game is daunting. Consider that the 30,000 genes in the human genome code for the activity of roughly 200,000 proteins. So far, scientists have discovered small molecules that interact in a predictable way with only about 500 proteins.

DAVE LAURIDSEN (MCKEARN); DAVID DEAL (COLLINS)

"HOW DO YOU MAKE FUNCTIONAL AND THERAPEUTIC SENSE OF THE WHOLE HUMAN GENOME? IT TAKES TIME AND CAPITAL. ACADEMIA HAS TIME BUT LACKS CAPITAL. PHARMA HAS CAPITAL BUT NO TIME." —CHRISTOPHER AUSTIN

Kalypsys's technology could change that. Walking up to a thick door near the company's main entrance, McKearn touches his index finger to a fingerprint scanner and swipes his identification badge through the door reader. Where McKearn's face should be, the badge has a picture of Dr. Evil from the Austin Powers films, a nod to McKearn's "evil plan" to disrupt traditional drug discovery and outcompete large drug companies. Inside the room are three large yellow robot arms standing at attention. Every few seconds, one of the robots springs to life, using a mechanical gripper to lift a small tray of chemicals out of a storage unit and swiveling to stack it at the next testing station.

On this day, the machines are doing tests on blood cells from leukemia patients and proteins suspected to be involved in the disease. One robot gathers 9-by-13-centimeter trays, dispensing samples—some proteins, some whole cells—into 1,536 tiny wells. The samples have been designed or modified to fluoresce when a protein's activity is altered or there is a physical change in a cell. In another set of trays are small molecules, which a second robot squirts into the samples; it puts the resulting mixtures into an incubator. After the prescribed incubation time, the third robot picks up the test mixtures and places them in an optical chamber, where they are examined by highly sensitive cameras. A central computer coordinates the robots and records the results of the tests.

The system allows the researchers to investigate a wide range of compounds and targets—and kill off dead ends—fast. "We were quite impressed," says NIH's Collins. For one thing, only one person needs to be present to start the machine, as opposed to the dozens of workers needed to run most big screening systems. The system operates day and night, screening a million compounds every day, which is more than many large drug companies can do.

After a long day, Simon Tisminezky, Kalypsys's business development manager, leads a tour of the company's manufacturing plant, a few kilometers away. This is where Kalypsys is building next-generation screening machines for itself, NIH, and a few other customers; it delivered a similar system to Merck in mid-2004. The facility, a cross between an airplane hangar and an auto mechanic's garage, is dark and empty after hours. So far, workers have completed incubators and storage units for the NIH system. By winter, Kalypsys plans to have a complete robotic system up and running; engineers will test the whole platform, then take it apart and ship it to NIH piece by piece.

Because its business plan calls for this sort of technology transfer, Kalypsys is building more than a machine: it's building a gateway between basic research and drug development. It will give a new community of scientists unparalleled access to the world's most advanced tools for probing the genome. Those tools could eventually change the way science *and* drug discovery are done. After the tour, Tisminezky is careful to set the security alarm as he leaves the facility and steps out into the setting sun.

NEW GENES, NEW DRUGS

If Kalypsys is building the gateway, then NIH is the gatekeeper. From the fourth floor of NIH's building 31, Francis Collins's office looks out over the institute's tree-lined campus in Bethesda, MD. It is a sweltering August day. Pictures of Collins and his family, his diplomas, and countless awards line the walls and shelves. But Collins is nowhere to be found.

It seems he has passed the day-to-day direction of what could be called the Human Genome Project, Act Two, to his deputies. In walks the Chemical Genomics Center's Austin with Jim Inglese, who is second in command and likewise a former Merck researcher. In a dress shirt and slacks, Austin has a casual air that belies the depth of his experience in genomics and drug discovery. He makes football analogies about where the "handoff" should occur between academic research and industrial drug development. He refers to Collins as "king" and "big guy." He jokes that he chose Kalypsys because of the San Diego weather.

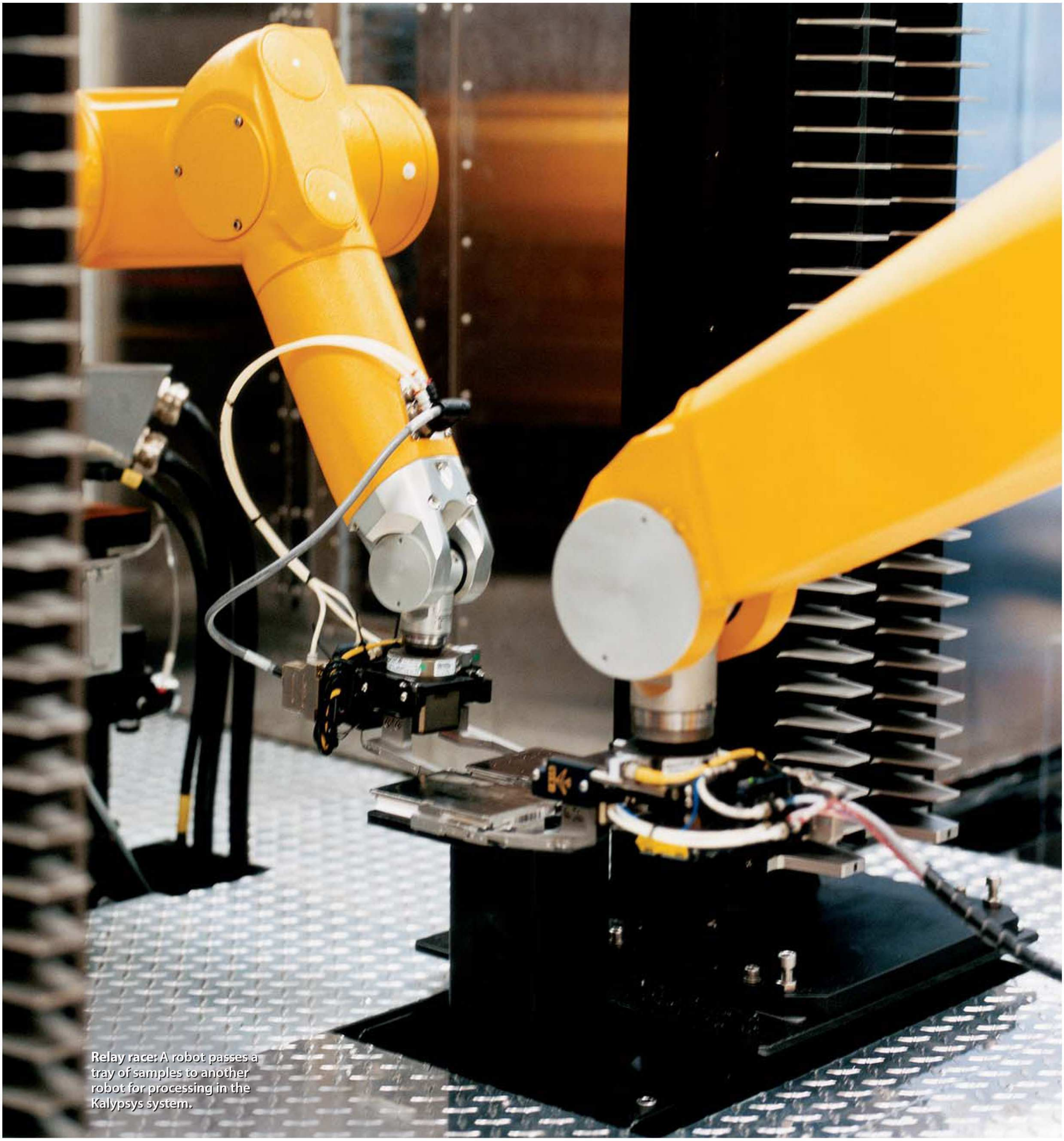
When the talk turns to the NIH initiative, though, Austin is all business, armed with charts and timelines to make his points. "The question of the day is, how do you make functional and therapeutic sense of the whole human genome?" he says. "It takes time and capital. Academia has time but lacks capital. Pharma has capital but no time." The right technology, he says, could change the terms of that equation. Once the NIH-funded network is up and running (Austin plans to fund five or six centers by next year), academic groups will compete for the opportunity to use the Kalypsys machines and other screening technologies—gaining capabilities previously reserved to industry.

That could lead to a wider variety of drug compounds for industry to work on, says Inglese, an expert on biomolecular screening. Instead of chasing frivolous cash cows like anti-impotence pills, companies might be able to derive huge benefits from developing treatments for cancer, diseases of the immune system, and other ailments. And because the new drugs will be based on small molecules, scientists know they will work, instead of knowing that they *should* work, as is the case with many large-molecule biotech drugs in development.

But Austin and Inglese bristle at the suggestion that their initiative signals a government move into drug development. They maintain that companies will still do the vast majority of the work needed to refine and develop drugs. Instead, what the NIH effort seems to demonstrate is that the border between basic science and technology development is shifting. Perhaps that shift is overdue; the biotech industry, for one, has suffered from premature efforts to translate molecular biology into useful therapies.

Whatever the implications, this follow-up to the genome project is near and dear to Collins. Big questions remain, he says: "How does the one-dimensional genome function in four-dimensional space and time? How does that go wrong? What can

DAVID DEAL (AUSTIN); DAVE LAURIDSEN (RELAY RACE)



Relay race: A robot passes a tray of samples to another robot for processing in the Kalypsys system.

be done to fix it?" Asked to predict how the effort will play out, Collins answers as both a scientist and a physician. "In a decade, we'll learn a substantial amount about how genes work together and how a cell does what it does," he says. "We'll understand the hereditary contribution to diseases such as diabetes and mental illness."

Will this new marriage of genomic science and drug discovery be a happy one? What bodes well for it is that, ultimately, the two disciplines have a common goal. Back at Kalypsys, McKearn is gathering himself for an off-site meeting. One might ask, in the end, what is really special about what he's doing. "The end customer for us is the patient," he says. "We can touch the lives of millions of people in a way that's unparalleled. That's what's keeping us going. We're not in it for the glory. It's a quest."

Gregory T. Huang is a *TR* associate editor.

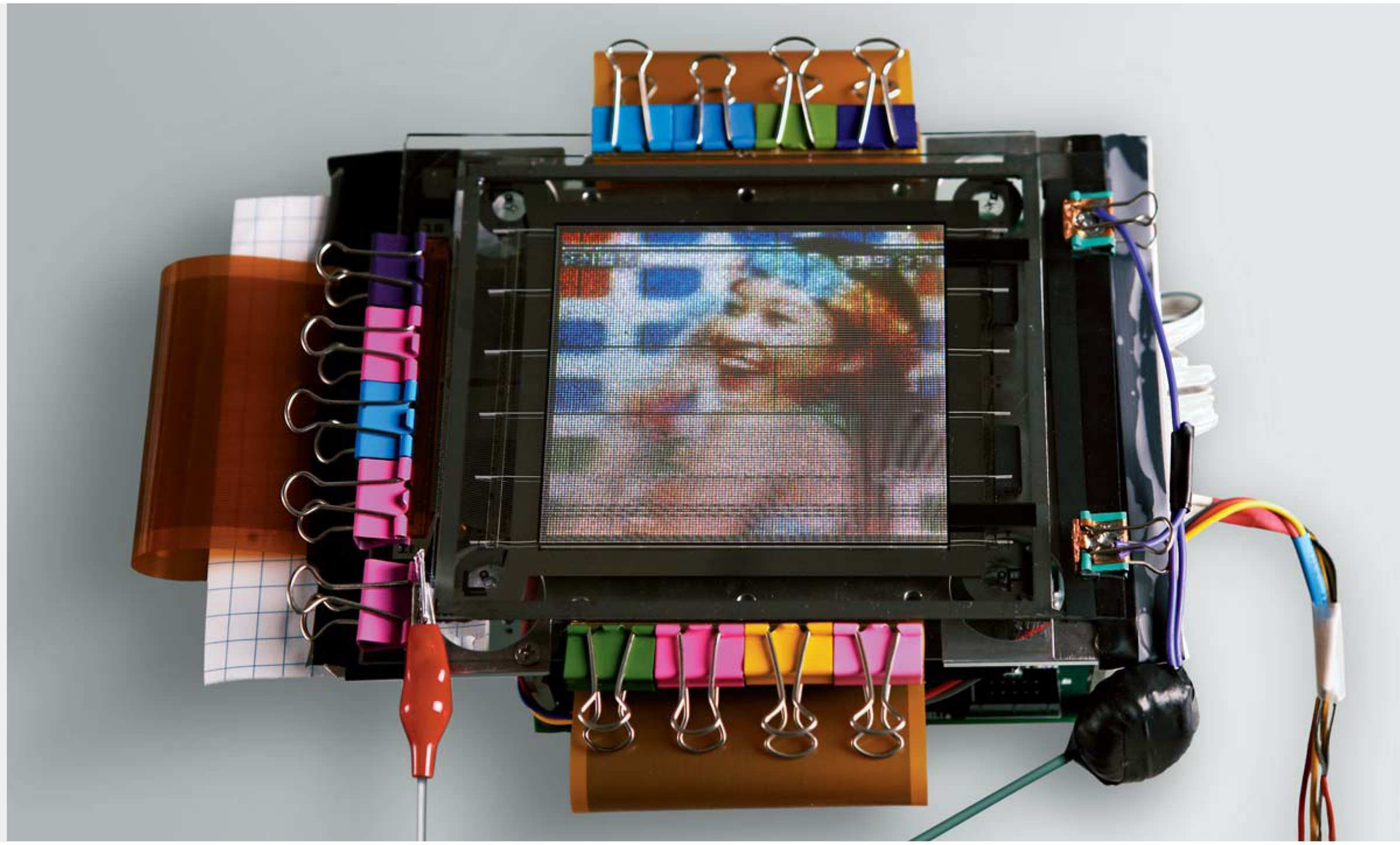
NANOTECH

IN THE SAMSUNG Advanced Institute of Technology, south of Seoul, South Korea, what looks from a distance like an ordinary 38-inch television plays an endless loop of commercials for James Bond movies. Like the displays increasingly common in American homes, it is a big, flat rectangle of color and motion in a high-tech plastic frame. But unlike the images on an ordinary TV, the ones on this lab model are generated by a layer of carbon nanotubes shooting electrons at a phosphor screen like so many tiny cannonballs. Around the world, television screens are emblems of stodgy domesticity. But this one is in the vanguard of tomorrow's nanotechnological revolution: it could be the first commercial product that brings nanoscale electronics into the middle-class home.

Researchers around the world are racing to perfect this novel type of display, which should be brighter, sharper, and less power-hungry than current flat-panel TVs. For the moment, though, the Samsung institute appears to have the lead. "They are the ones to beat," says Yahachi Saito, lead researcher of a rival group at Nagoya University in Japan. "They have moved very quickly."

Samsung, and South Korean technology firms in general, are rarely thought of as the leading developers of hot new technologies. This is a stereotype, however, that the company is determined to change. "We are still identified, correctly, with low-cost manufacturing," says Young Joon Gil, chief technology officer at the Samsung institute. But as competitors emerge from China and other east-Asian countries, he says, Samsung "must gradually move to high-profit, high-risk innovation to survive."

Nanotechnology is the most important of the risky disciplines the company hopes to mine for new products, and the nanotube TV screens are its first fruits. Known as "field emission displays," they should be in stores, Young says, by the end of 2006, comfortably ahead of the competition.



TV tubes: Electrons from carbon nanotubes light up this prototype, a smaller cousin of Samsung's closely guarded display. »

ON DISPLAY

SAMSUNG'S CARBON-NANOTUBE TELEVISION COULD MAKE THE COMPANY'S OWN LUCRATIVE LIQUID-CRYSTAL AND PLASMA DISPLAYS OBSOLETE. THAT'S NOT STOPPING IT.

BY CHARLES C. MANN PHOTOGRAPHS BY VIRGILE SIMON BERTRAND

Meeting that prediction will not be easy. Simply taking field emission displays from the laboratory to the retail floor will require solving a host of tough technical problems. Moreover, current flat-panel displays, based on liquid-crystal and plasma technology, are constantly becoming better and cheaper, meaning nanotech researchers will have to work harder just to keep up. Even success would create its own set of problems, since Samsung—one of the world's leading manufacturers of liquid-crystal and plasma displays, as well as ordinary cathode-ray-tube TVs—will be competing against *itself.*

Nanotech displays are thus both a harbinger of a technological revolution to come and an example of how a major electronics company—with lucrative, established markets to protect—is trying to manage and contain that revolution. "We believe we must master this field to grow," Young says. "But at the same time we cannot let it wreck our company. We have to watch *very* carefully."

GUNNING FOR THE FUTURE

Field emission displays are an old idea that suddenly became more attractive in 1991, when Sumio Iijima, an electron-microscope specialist at NEC Research in Tsukuba, Japan, discovered that carbon molecules could link together into long, thin cylinders later dubbed nanotubes. (The "nano," like the "nano" in "nanotechnology," comes from "nanometer," a billionth of a meter.) The tubes were like tiny sheets of carbon molecules that had been rolled up into cylinders one-ten-thousandth the width of a human hair. Scientists quickly learned that these unusual structures had a host of interesting properties, including great strength, and high electrical and thermal conductivity.

But what attracted Saito, the Nagoya researcher, to carbon nanotubes was the possibility that they could act as electron guns. Placed in a properly aligned electric field, theoretical physicists said, the little tubes should shoot out electrons like hoses emitting streams of water. Many materials emit electrons when sufficient voltage is applied; the difference, the physicists said, is that nanotubes should actually accelerate the particles along their lengths, which would allow them to emit electrons of sufficient energy to activate phosphors in very low-voltage fields. Saito, now a professor of quantum engineering, first publicly demonstrated this effect in 1998. Working with Noritake, a big Nagoya ceramics and electronics firm, he assembled a small array of nanotubes that shot electrons into a phosphor screen, creating a bright light.

Saito's experiments had an obvious commercial target: the \$61-billion-a-year world market in television sets. The cathode ray tubes inside traditional TVs have changed little since they were invented in the 1920s—in stark contrast to almost every other piece of consumer electronic equipment. They shoot electrons from the tips of wires onto phosphor screens, creating patterns of glowing dots that the human eye interprets as moving images. Cathode ray tubes are inherently bulky, because the electron gun must sit back far enough to hit the entire screen. As a result, the picture tube in a typical home-theater screen is a massive object that almost fills a room; manufacturers believe the devices would be more popular if they were more manageable.

To make thinner, lighter big-screen TVs, manufacturers have turned to plasma and liquid-crystal displays, but these have their own drawbacks, beginning with their high price *(see "Screen Test," p. 65)*. Plasma screens, for example, are vulnerable to "burn-in," in which motionless images, if displayed for too long, become seared permanently into the glass. They also consume as much as 700 watts of power, enough to make some critics worry about the environmental consequences if the displays were widely adopted. In LCDs, meanwhile, pixels switch relatively slowly from one color to another, which causes fast-moving images to smear or leave ghosts as the cells fail to keep up with the action.

Field emission displays will, in theory, solve many of these problems. They aren't vulnerable to burn-in, and they use much less power. At the same time, the pixels in a field emission display can turn on and off faster than those in a liquid-crystal display, meaning that fast-moving images don't smear. And those images can be viewed from any angle, while liquid-crystal displays require viewers to be directly in front of the screen.

But getting carbon nanotubes to shoot electrons at a screen in an actual consumer TV will require scores of innovations in several fields—the kind of effort often best coordinated by very large companies. Indeed, about the time that Saito produced his first field emission display, he learned that he faced competition from an unlikely place: South Korea.

BEYOND THE SWEATSHOP

South of Seoul, the urban grit of the capital gives way to lush, rolling, low hills dotted with office parks that would not be out of place in a suburb of San Francisco or Boston. In the planned community of Kiheung, one especially large complex—a set of four low, parallel structures cut through by a central corridor—houses the Samsung Advanced Institute of Technology, probably Korea's premier private research center.

The institute is largely the vision of Samsung chair Lee Kun Hee, who established it soon after he took the company's helm in 1987. Samsung is one of South Korea's *chaebol*, the giant family-controlled holding companies that still dominate the nation's economy. At the time of Lee's accession it was, like most Korean electronics companies, an exemplar of what is sometimes dismissively referred to as "sweatshop electronics"—taking advantage of the nation's low wages to undercut manufacturers in wealthier areas. It sold most of its products as commodities to better-known corporations, many of them in nearby Japan, which stuck them in boxes and slapped their own names on them.

Lee, the third son of Samsung's founder, argued that the company's—and Korea's—growing success would inevitably attract competition from even lower-wage nations, especially China. Samsung, he said, would have to enter new businesses to survive; "Change everything except your wife and children!" was his rallying cry. In practice, this meant concentrating on higher-end, higher-profit products. Samsung would have to become a brand name, a symbol of quality like Sony or Honda.

To that end, Lee argued, Samsung would have to innovate, which in turn meant drastically increasing its research and development efforts. The Samsung Advanced Institute of Technology was the logical result. Slowly but constantly expanded

“WE BELIEVE WE MUST MASTER THIS FIELD TO GROW. BUT AT THE SAME TIME, WE CANNOT LET IT WRECK OUR COMPANY.”

—YOUNG JOON GIL, CHIEF TECHNOLOGY OFFICER, SAMSUNG ADVANCED INSTITUTE OF TECHNOLOGY

Glow business: In a test chamber, Samsung researchers measure the volume of electrons emitted by the layer of carbon nanotubes behind the white screen.

since its creation, the laboratory now employs 950 staff, about a quarter of whom work on Samsung's core business of semiconductors (the company is the world's biggest manufacturer of random-access memory chips). According to company representative Lee Hyunji, institute researchers collaborate with about 120 universities and research centers in 15 countries.

Samsung now sells cutting-edge products, from superthin DVD players to video game chips. It has become the world's third-biggest cell-phone manufacturer, with a wildly popular premium line of handsets with crisp color screens. In a list of the "most admired" electronics companies of 2003, *Fortune* magazine ranked Samsung fourth in the world. Samsung spent $2.9 billion on R&D in 2003; gross sales that year for the Samsung group as a whole rose almost 11 percent from 2002, to about $55 billion.

FILLING THE VACUUM

Field emission displays exemplify the next step Samsung seeks to take in its corporate transformation from a high-tech competitor to an industry leader. "Display technology is hugely complex to begin with," says Kim Jong Min, vice president and director of the materials lab at the institute. "And using nanotubes adds to that enormously, both because of the unavoidable problems that always come from exploring an unfamiliar area and the fact that here there is no model to follow." According to Kim, nanotube-based field emission displays are so complex that no single firm can develop them by itself. In consequence, researchers around the world are splitting the technology into its components and informally assigning different groups to work on each one. Samsung, for instance, does not plan to make its own nanotubes, except for research purposes. Instead, it will buy them in powder form from Carbon Nanotechnologies, a Houston-based firm with a considerable arsenal of patents in the field. A gram of carbon nanotube powder, enough to make half a dozen 40-inch displays, cost $100 last year, Kim says, but will sell for less than $10 in two years. "That is a competition we won't enter."

Similarly, Samsung does not intend to focus on the glue that affixes the tiny tubes to their glassy base, itself a sticky technological challenge. The company is working with DuPont to come up with an adhesive that's thin enough to spread, strong enough to hold the ultrathin tubes by their ends, resilient enough to retain its grip despite inevitable expansion and contraction from heat, and easy enough to remove that manufacturers can clean stray adhesive from the tops of the nanotubes, so they can spray out electrons.

Nor is the company trying to gain an advantage by developing the physical components of the display itself—the spacers that hold apart the top and bottom sheets of the screen, the high-vacuum packaging, the driver circuitry, and other standard field emission components and materials. Instead, it has joined a consortium of more than half a dozen European companies and universities created specifically to tackle those problems and incorporated the group's early results into the 38-inch display now showing off Pierce Brosnan's Bond-blue eyes.

Delegating these aspects of field emission display design still leaves plenty for Samsung to work on, beginning with the glass itself. The nanotubes have to shoot their electrons across a vacuum; otherwise they would be absorbed or deflected by air molecules. Yet making what amounts to a very wide, sheetlike vacuum chamber is difficult, because over a large area air pressure will tend to crush together the two sides of the screen. The obvious answer is to put a support pillar in the middle of the screen. But then, Saito explains, "you see the support in the middle of the picture."

Equally problematic, in his view, is the thermal expansion and contraction of the display. When the nanotubes are emit-

SCREEN TEST

Cathode ray tubes have dominated TV display technology for nearly 70 years, but today they're locked in a four-way race for the future of home entertainment.

	CATHODE RAY TUBES	LIQUID-CRYSTAL DISPLAYS	PLASMA DISPLAYS	FIELD EMISSION DISPLAYS
HOW THEY WORK	An electron beam steered by magnetic fields strikes phosphors on a glass screen	Polarized light shines through liquid-crystal "gates" that control pixels' color and intensity	An electric pulse sets off a burst of ionized gas in each pixel, as though it were a tiny neon sign	Carbon nanotubes glued to a substrate shoot electrons at phosphors on a glass screen
STRONG POINTS	▪ Reliable ▪ No burn-in ▪ Viewable from any angle ▪ Inexpensive ▪ Phosphors can display fast motion	▪ Thin ▪ Light ▪ Reliable ▪ No burn-in	▪ Thin ▪ Viewable from any angle ▪ Pixels switch quickly ▪ Sharp, bright images	▪ Thin ▪ Light ▪ No burn-in ▪ Viewable from any angle ▪ Pixels switch quickly ▪ Low power consumption
WEAK POINTS	▪ The electron gun must sit far behind the screen, making tubes bulky and heavy	▪ The viewer must be positioned directly in front of the screen ▪ The pixels switch slowly, smearing fast-moving images ▪ Expensive	▪ High power consumption ▪ Burn-in (motionless images displayed for too long become seared into the screen) ▪ Expensive	▪ Unsolved technical problems, such as maintaining a vacuum between substrate and glass ▪ Cannot currently be manufactured affordably

NANOTECHNOLOGY CAN BE "A **DISRUPTIVE TECHNOLOGY** FOR DISPLAYS. BUT THE CONVENTIONAL METHODS CAN **DISRUPT IT BACK.**"

—**KIM JONG MIN**, VICE PRESIDENT AND DIRECTOR OF THE MATERIALS LAB, SAMSUNG ADVANCED INSTITUTE OF TECHNOLOGY

ting electrons, the display gets hotter, and all its materials expand; when the electron beam is off, they shrink. "The problem is how to accommodate the expansion," Saito says. His team had to find materials whose thermal expansion coefficient was the same as that of glass, so that the entire display would expand and contract in concert.

Exactly how Samsung pulled all these pieces together is "our secret," says Kim. "That's what we do: we're a company that makes devices." But key to Samsung's decision to focus on field emission displays, he admits, is the lucky fact that they can tolerate imprecision. With current technology, aligning the nanotubes across the back of the display is an inexact process. The tubes point in a jumble of different directions, and most are too broken or bent to emit electrons successfully. Fortunately, nanotubes are small: about 10,000 cover each pixel in the display. As a result, Kim says, "We expect that only 30 to 50 percent of them will work, but we only need 30 to 50 percent to light up the pixel and deceive the human eye."

Samsung is pleased enough with the result to permit a journalist from *Technology Review* to be the first non-Korean reporter to visit the Advanced Institute of Technology. Walking through the institute's maze of small fluorescent-lighted laboratories, each with its coterie of white-coated researchers and glowing computer screens, Kim says that the display consumes about 100 watts, about a third of the power required for an average plasma screen of comparable size. "That's just for now," he adds. A bare two millimeters thick, the glass of the screen is thin enough to make the display slimmer than anything now on the market.

Arriving at the display, Kim introduces it with the slight anxiety of a proud parent hoping that strangers will appreciate the special qualities of his offspring. The image is as sharp as those produced by traditional high-definition picture tubes with similar display sizes, though the screen has several small blank spots. ("Prototype difficulties," Kim explains.) Asked whether the technology is almost ready for market, the scientists in the room look at each other uncertainly. Samsung, Kim finally says, has just begun to work on the real challenge in bringing nanotechnology to the world: making the product affordable. The economic problems, he says, "are much, much harder than the technological ones."

LUCKY $7

Samsung is not alone. Two hours away in Japan, Saito's success—and fears of being eclipsed by Korea—led the government's New Energy and Industrial Technology Development Organization to establish a $37 million, 2.5-year national project to crash-develop field emission displays. Launched in 2003, the project has four main participants: Hitachi; Asahi Glass; a Nagoya University-Noritake collaboration directed by Saito; and a joint effort by Mitsubishi, Kyoto University, Osaka University, and Osaka Prefecture University. "The Koreans are still ahead of us," Saito says. "But we are working hard to catch up."

So are a dozen other companies in Japan, Europe, and the United States. It is generally believed that the leaders are Noritake, Mitsubishi, Motorola, and the French Atomic Energy Commissariat's Laboratory of Electronics and Information Technology in Grenoble. Motorola demonstrated a small prototype in 2002; last year, the French laboratory demonstrated several, as did a small, secretive Silicon Valley startup, cDream.

Nanotechnology is frequently described as a technology with the potential to capsize the established order. In a theory often touted by business consultants, an industry's largest incumbents are unlikely to develop such technologies, for two reasons: first, they are less profitable in their initial stages, and second, they have the potential to undermine existing products. Eventually, a small startup does develop the technology, using its sharp technological edge to overwhelm the competition and ultimately rocking the establishment.

Whether field emission displays fit this model remains to be seen. Nanotubes have obvious technological advantages on paper, but in the marketplace they are far from overwhelming. Right now, 42-inch plasma displays typically retail for $2,500 to $3,500; large liquid-crystal displays range from about $5,500 to $7,000. But the cost of both technologies is plummeting. "The manufacturing cost per diagonal inch of plasma displays will be about $9 in 2005 and 2006," Kim says. "But because we have startup costs, we have to beat that by a considerable margin—$7 a diagonal inch, say."

Luckily for Samsung, production methods for field emission displays are similar enough to those for plasma displays that it can use one of its current fabrication plants to build the devices, avoiding the overhead costs of an expensive new factory. Yet if plasma displays keep getting cheaper, Kim says, "we will lose our opportunity," and field emission displays will not replace them. And even if Samsung reaches the magic $7 number, he says, to stay competitive it'll have to shoot past it, to perhaps $5 per inch. Nanotechnology can be "a disruptive technology for displays," Kim says. "But the conventional methods can disrupt it back."

Indeed they can. In July, Samsung SDI, the company's display subsidiary, announced that next year it will introduce a standard CRT for a 32-inch television screen that is only 14 inches deep, half the depth of existing picture tubes. Televisions with the new "Vixlim" tube, the company promised, will shrink from two feet in depth to 15 inches; they will also have better-quality images than either plasma or liquid-crystal displays and be up to a third cheaper. By the end of 2005, Samsung SDI predicts, the new tubes will be in every large standard television it makes. Standard picture tubes, according to company representative Lee, will enter a "new boom period."

Asked about the new Samsung CRT, Kim emits a mock groan. "They are very good researchers," he says. If field emission displays cost three times as much as CRTs and are only somewhat thinner, he acknowledges, nobody will buy them. Still, he believes that by covering its bets, the company as a whole will come out a winner. So will the consumer, who will enjoy steadily falling prices. In Kim's view, field emission displays will eventually prevail, becoming the leading edge of an approaching wave of nanotechnological products. But the race will be a lot closer than subsequent business histories will make it seem. TR

Charles C. Mann is a *TR* contributing writer. He spent the last year living and writing in Tokyo, Japan.

MAGNETIC BRAIN IMAGING

FLUTTERS IN THE FAINT MAGNETIC FIELDS AROUND THE BRAIN MAY HELP GUIDE SURGEONS TO THE PRECISE SPOTS WHERE EPILEPTIC SEIZURES START—AND NEUROLOGIST **WILLIAM SUTHERLING** IS USING A POWERFUL BUT LITTLE-KNOWN TOOL, MAGNETOENCEPHALOGRAPHY, TO PROVE IT.

AN EPILEPTIC SEIZURE IS THE OUTWARD SIGN OF AN ELECTRICAL STORM in the brain, a sudden surge of uncontrolled electric currents. If neurosurgeons can pinpoint the damaged brain tissue that sparks the storm, they can remove it, potentially sparing a patient a lifetime of debilitating attacks and antiseizure medications. But zeroing in on the precise bits of defective gray matter using the scalp electrodes of a standard electroencephalograph (EEG) machine is difficult, because electrical fields generated in the brain "get spread out and distorted" as they pass through the skull, says William Sutherling, a neuroimaging expert at the nonprofit Huntington Medical Research Institutes (HMRI) in Pasadena, CA. So Sutherling looks as well to the *magnetic* fields generated by each electrical impulse in the brain; those pass through the skull virtually unaffected. Using one of only a few dozen magnetoencephalography (MEG) machines in the world, Sutherling is measuring the vanishingly faint magnetic fluctuations generated by epilepsy sufferers' brains, and combining that data with 3-D information from magnetic resonance imaging (MRI). His hope is to prove that the method is a reliable, practical way to narrow and delimit the sources of seizures, so that surgeons can remove the offending tissue without damaging the healthy, functioning cells around it. This fall, Sutherling gave *TR* senior editor Wade Roush a tour of HMRI's $2.5 million MEG facility and demonstrated how his team gathers data from the hopeful patients who venture into his chamber.

PHOTOGRAPHS BY MISHA GRAVENOR

1

1. A ROOM WITH NO VIEW. Sutherling strides into the MEG chamber, a magnetically shielded room-within-a-room with an interior floorspace of about 10 square meters. The room houses HMRI's whole-head MEG unit—so named because its array of internal sensors fits snugly over a patient's head like a giant hair dryer. The sensors detect even the tiniest changes in any magnetic fields threading through them. Such fields are normally all around us, so tracing fluctuations to specific areas of the brain with millimeter-scale accuracy would be impossible unless the sea of ambient magnetic waves generated by fluorescent lights, computers, power lines, and the earth itself—not to mention the nearby MRI machine, which is essentially a giant magnet—were kept out.

2. MAGIC METAL. The secret to shielding the MEG unit, Sutherling explains, is a thin layer of an alloy called "mu metal," visible between the blue exterior pane and the layer of white foam on the edge of the room's bank-vault-like door. Once the door is closed, exterior magnetic fields flow around the mu metal cage, leaving the interior magnetically silent.

3-4. HEAD COLD. Superconductivity is the key to the MEG unit's exquisite sensitivity. At the core of HMRI's unit, built by VSM MedTech of Coquitlam, British Columbia, is an array of small metal rings called superconducting quantum interference devices, or SQUIDs, which look much like the suckers of an actual squid's tentacles (3). When a ring is cooled to temperatures just above absolute zero, it becomes a superconductor, meaning that an electrical current traveling around it encounters virtually no resistance and could, in principle, keep circling forever. That current, in turn, produces a magnetic field. "If a magnetic field spreads through from the brain, it opposes the magnetic field already in that ring," says Sutherling. "And the ring reacts by trying to keep the total current going through that ring the same." Any new current induced in the ring causes a change in voltage that can be amplified thousands of times over and precisely measured by electronics. To stay superconducting, the SQUIDs must reside inside a huge flask of liquid helium, Sutherling says, touching the ungainly—and frosty—apparatus that fits around the patient's head (4).

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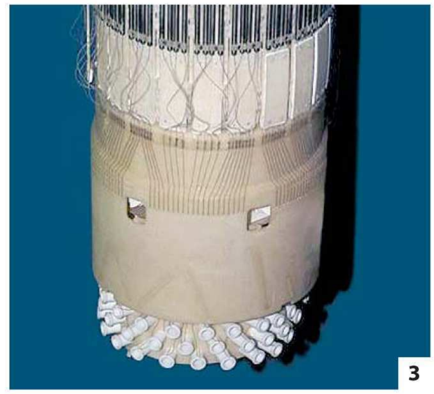

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5. ANOTHER REASON TO BRUSH. Before a patient is seated in the MEG unit, every piece of metal on his or her body must be demagnetized.Otherwise, the merest jiggle would break the magnetic calm. MEG technician Nancy Lopez has a handheld demagnetizer for this purpose; it's powerful enough to neutralize even a patient's dental fillings.

6. SOUND CHECK. The first step in a MEG exam is to plumb the patient's brain for fixed reference points, needed later to align the MEG data with MRI images and reckon the locations of electrical disturbances. Lopez outfits a subject with headphones so that she can administer a series of tones, which cause the brain's auditory centers to sprout magnetic fields.

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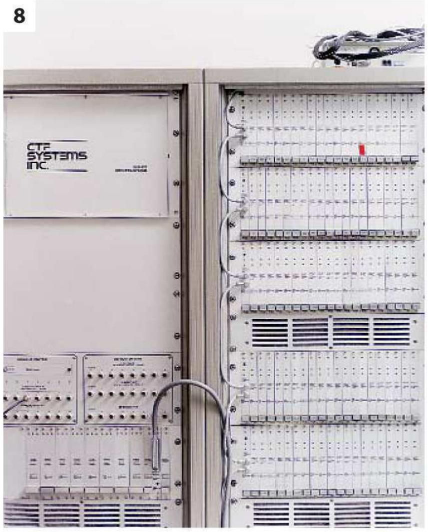

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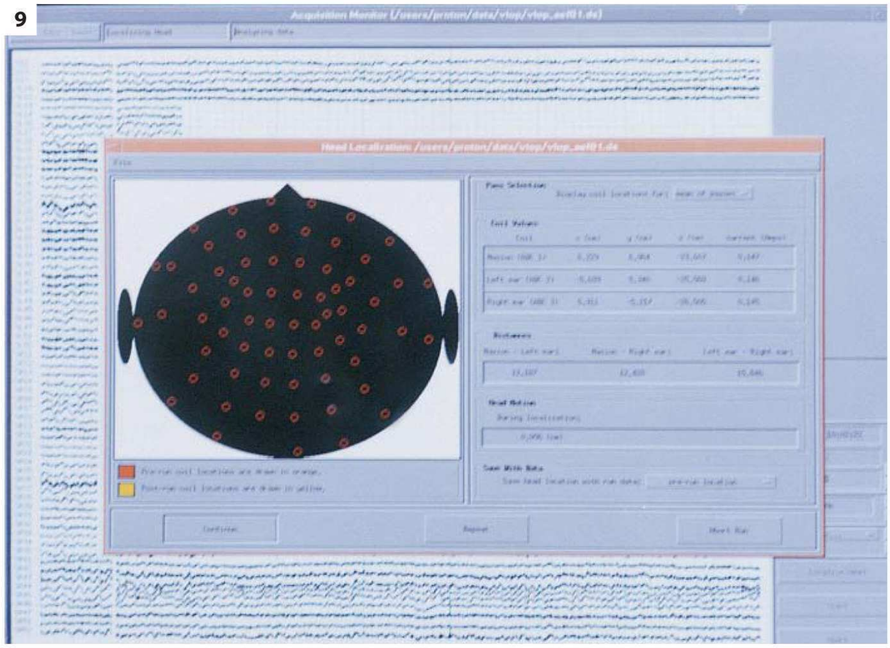

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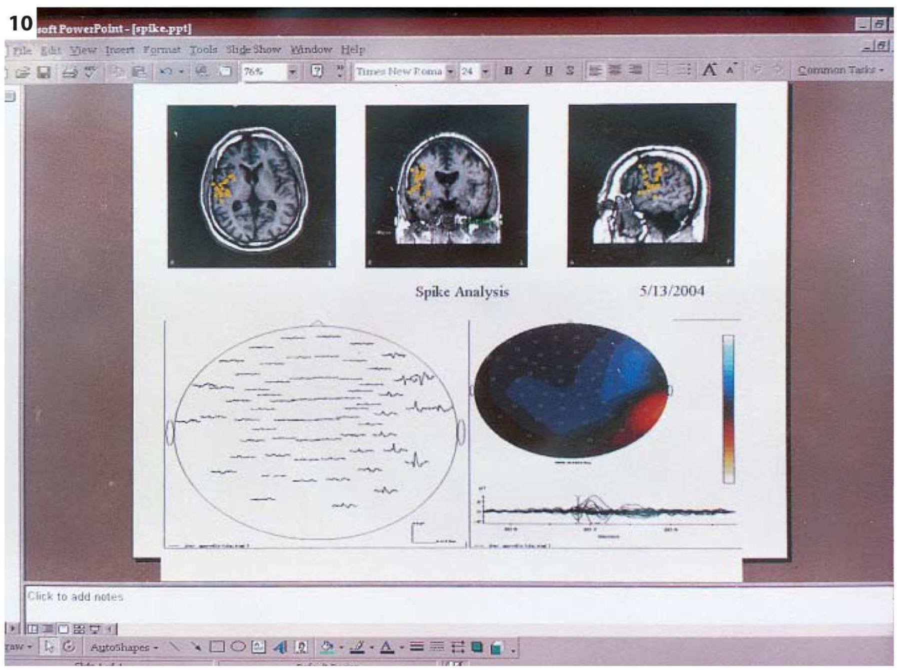


These centers—which are well-known landmarks in the brain, always located on specific folds in the right and left temporal lobes—show up clearly on the MEG unit's computer readout.

7. ELECTRIC DREAMS. For the next hour or two, the patient must sit absolutely still—it's okay to doze off—while the detector array observes the brain's spontaneous electromagnetic activity.

8. NUMBER CRUNCHER. Each of the SQUIDs sends its readings to a separate board in the MEG unit's main computer, a refrigerator-sized behemoth across the room from the MEG chamber.

9. SKULL CAP. At a bank of desktop and laptop computers adjacent to the main computer, Lopez and Sutherling open windows depicting the MEG unit's measurements graphically. A map caricaturing a top view of the subject's head, complete with a tiny triangular nose and elephant ears, shows the detectors' locations around the skull as red circles. In another window, the changing readings from each individual detector are expressed as squiggly, EEG-like lines. The relatively flat readings from this healthy volunteer indicate that she's asleep.

10. A PASSING STORM. Conditions are quite different during a seizure. To illustrate, Sutherling calls up the records of an actual epilepsy patient examined in HMRI's MEG unit before surgery. Rather than wait for a patient to have a spontaneous seizure during the exam, doctors implant a grid of electrodes just inside the skull, over the region of the brain thought to be affected. A jolt from these electrodes induces a miniseizure whose magnetic signature can then be recorded in detail. The individual SQUID readings from these small seizures are translated by software into a schematic showing where the strongest magnetic fields emanate from the skull.

Pointing to the three views of the head at the top of the screen, Sutherling explains that the magnetic readings are mathematically transformed into three dimensions and overlaid on MRI images of the patient's brain. The stark yellow markings then guide surgeons to the wellsprings of a patient's epileptic seizures—usually tiny bits of scar tissue.

Sutherling recalls one lifelong epilepsy sufferer whose seizures struck every two hours. EEGs showed unusual activity across the man's frontal lobes, but MEG images traced the problem to a single spot in the left frontal lobe, near the speech center. Surgeons excised most of the scarred tissue while avoiding cuts that might have affected the man's ability to speak. After the operation, he experienced only minor seizures. "Ideally, we want to make certain that the area that's removed has zero function—that it's just scar tissue—and that the removal is complete," says Sutherling. "The goal is to make people seizure-free, so that they're able to drive and able to work." TR

Picking Your Brain

BY ERIKA JONIETZ | Photograph by Kate Swan

TECHNOLOGY REVIEW: A company called Cyberkinetics received U.S. Food and Drug Administration approval in April for a clinical trial of a brain implant designed to allow paralyzed patients to interact with a PC. Is the technology really advanced enough to make this sort of test ethical?

PAUL ROOT WOLPE: There are issues with device testing of this kind in terms of human-research protection. The kinds of people that these devices tend to be tested on are deeply coerced by the nature of their disabilities. I don't think it's insurmountable; all medical progress depends on somebody being the first one to try a new technology. What is crucially important is really good oversight and really good informed consent. Given the history of oversight and of informed-consent issues with medical devices, it does concern me that these technologies will be used without strong external review and monitoring.

TR: Isn't this technology at a much earlier stage than where you would test a drug?

WOLPE: Generally in bioinstrumentation, that happens. For historical reasons, we are much, much more concerned about people ingesting drugs than we are about subjecting them to bioinstrumentation, and we have different regulations about how to test them and protect subjects. Pharmaceuticals alter the basic chemistry of our bodies; bioinstrumentation, until recently, was primarily external to our bodies. The problem is, the nature of bioinstrumentation is about to change, and emerging biotechnologies will be incorporated into our bodies much as pharmaceuticals are. Ten, 20, 30, or 50 years from now, perhaps, nanotechnology will develop little nanobots that are injected into our bodies to roto-rooter out our arteries. Would these be a drug or a bioinstrument? We need to begin to change the way in which we think about bioinstrumentation in general. We have to rethink our tendency to be less rigorous about applying bioinstrumentation to the human body than drugs. Right now, even these new technologies that may have profound effects on our brains do not have the degree of oversight that drugs do.

TR: But the payoff seems huge.

WOLPE: For people who are paralyzed, the Christopher Reeves of the world, the ability to manipulate things in the world with the mind is an extraordinarily desirable outcome. Implants for people who have locked-in syndrome—so they can't communicate with the outside world—are being tested right now and allow the subjects to directly translate brain impulses into computer responses, such that they can move a cursor around a screen and choose phrases, simply through thought. That is certainly a wonderful thing. It would be churlish to say, Let's not allow this person to communicate because we're not sure what the long-term effect is of putting electrodes in his brain. You have to ask yourself the risk-benefit question. But those cases are different than neurotechnologies that might eventually become fairly common.

TR: What kinds of technologies are those?

WOLPE: A lot of the technologies we're talking about are communication technologies; they take information from the brain and externalize it for one reason or another. We also have internalizing technologies—cochlear implants, optic-nerve implants—whose purpose it is to take information from the outside and give us access to it. These two technologies will eventually come together, and then we'll have interactive-chip technologies, such that we'll have input-output interactions.

But in terms of what most people mean by brain-computer interfaces, there's a lot of work being done to create noninvasive BCIs by putting electrodes on people's scalps or having them wear these caps that are infiltrated with sensors. The goal is a system that could retrieve much more detailed and specific information from the brain so that people could do sophisticated kinds of work through thought alone. It's very promising for people who are paralyzed, but it also means that I could sit here at my computer with a cap on my head and answer the phone, "type" on my computer, be connected to my colleague in the office next door—through brain impulses alone. That's one area I think technology may take us over the next 50 or 60 years. We're going to be able to manipulate any system that has a sophisticated chip in it, everything from your wristwatch to your car.

PAUL ROOT WOLPE

POSITION: Professor, Departments of Psychiatry, Medical Ethics, and Sociology, and senior fellow, Center for Bioethics, University of Pennsylvania; chief of bioethics, NASA

ISSUE: Brain-computer interfaces. Neuroscientists and engineers are developing technologies that allow the brain to interact directly with computers, from chips that could enable amputees to control prosthetic limbs to devices designed to enhance brain function. How will these new technologies influence daily life?

PERSONAL POINT OF IMPACT: A founder of the field of neuroethics, which examines the implications of emerging neurotechnologies. Organized the first series of meetings on the topic in 1999 and 2000, bringing together leading brain scientists such as Steven Pinker, Steven Hyman, and Michael Gazzaniga.

TR: Will those kinds of devices raise ethical questions?

WOLPE: A key issue is the implications of these technologies for personal privacy. If there are eventually technologies that externalize internal states, who has a right to access that information? And what about cases where that information could be taken against people's will, or without their knowledge? Are we going to start implanting electrodes in the brains of the suspected terrorists in Guantánamo Bay? Certainly not yet—there's nothing we could get out of that. But research is being funded by the Departments of Homeland Security and of Defense for things like lie detection technologies using functional MRI or near-infrared light. These technologies can be used coercively in a way polygraphs, for example, can't. If you're not willing to cooperate with a polygraph, there's really nothing they can do. But you aren't necessarily going to need to cooperate for some of these technologies; they can, theoretically, be used covertly. They may be used on suspected criminals or enemies of the state, or on you and me when we're going through airports. Near-infrared technology may someday employ an undetectable spot of light on your forehead. Research on ways to take what used to be private thoughts and make them accessible will challenge our laws and our thinking about what privacy means.

TR: How does the societal impact of brain-computer interfaces compare to other areas of biomedical research, such as genetics or stem cells?

WOLPE: Neurotechnology is way ahead of genetic technology. We're not cloning anybody yet. We're not creating genetically modified human beings. Yet we are already testing implanting electrodes into people's brains. Unfortunately, there's only a fraction of the scrutiny by policymakers, legal scholars, ethicists, and the religious community towards neuroscientific advances that there is towards genetic advances. That's in some ways very, very troubling.

If I had your genome in front of me and did every test on it that I could think of, what could I really tell about you aside from your disease profile? Not much. We don't know how to look at a genome and tell if you're happy or shy or funny or extraverted. But we are beginning to be able to tell those things from brain scans. Brain technology is, before genetics, going to tell us things about people that they really consider to be private.

Another big issue is intervention: is it ethical to change fundamental aspects of who people are by changing their genomes? We still can't intervene in human beings genetically; even gene therapy has been, so far, largely unachievable. Our ability to manipulate the brain raises far more immediate questions about intervening in who we are fundamentally and what's the right and the wrong kind of intervention. People involved in the development of the technologies and people like me who study them need to spearhead a very open, public discussion so that society as a whole can begin to respond in ways that direct the research into productive and socially desirable avenues. TR

EXECUTIVE EDUCATION FOR TECHNOLOGY LEADERS

NOW MORE THAN EVER

BY CAROL HILDEBRAND

By now, CIOs ought to be used to rapid changes—in technology, in business, in world economics. But after the tectonic-plate shifts of the past few years, IT executives now look out on a corporate landscape that has changed nearly beyond recognition. Global economies have been buffeted by geopolitical events as well as a continuation of the Internet implosion that began three years ago. As the economy struggles to recover, companies have put the brakes on IT spending—technology budgets are largely flat or declining in the Fortune 500.

But corporate expectations about technology investments have only risen as senior executives look to any avenue to improve the bleak profit picture. Now, CIOs face intense pressure to spend frugally, and to seek IT projects and investments that promise an immediate return on investment. "With today's fluctuating IT budgets, project performance right out of the gates is critical," says Charles Breckling, director of marketing for executive education at the Harvard Business School in Cambridge, Mass.

In short, it's crucible time for CIOs.

"The pressure has undoubtedly intensified for them," says Donald Lessard, deputy dean of executive education at MIT's Sloan School of Management, also in Cambridge. "There's been a sharpening of focus as executives realize that IT is a key determinant in how a company does business and that it has to be considered strategic."

Indeed, the concept of strategic technology has grown in importance over the years, as IT moves from an operational cost center to a function with the potential to actually generate revenue for an organization.

"Technology executives need to move from simply supporting business initiatives to becoming more integrally involved in strategy and organizational design and understanding how IT can change the business," explains Lessard.

For example, Gerard McCartney, CIO of the Wharton School at the University of Pennsylvania in Philadelphia, works closely with CFO Scott Douglas to prioritize technology projects to fit business goals. "We always make sure that the projects we fund support those strategic objectives," says McCartney. The two biggest priorities are faculty research and student educa-

“These days, CIOs need to understand in great detail the various elements that drive a company's profit picture.”

— *Dave Miller*
Duke Corporate Education Inc.

tion, and that's where a large amount of funding goes—a decision that has paid off in spades. McCartney supported a project called WRDS, a data-mining tool that helps Wharton faculty do research. “There's nothing to compare to it,” says CFO Douglas. “When we sold it to other institutions for $30,000 a year, we knew we had a case for proving IT value. Now it's become a revenue generator.”

Executives who are looking for money under any possible rock love the idea of IT moving from the red to the black side of the balance sheet, but in order for that to happen, CIOs must undergo a sea change in their very job description. They must be able to boldly envision technological initiatives that provide competitive advantage, and they must do so within the fiscal straitjacket that is the order of the day at many companies. Moreover, they must do so in a world in which corporate and customer expectations of IT capabilities are very high indeed. It's not enough for CIOs to streamline the supply chain within their companies—now they must tightly couple their systems with those of their suppliers, partners, customers, and even competitors. Customers, in the meantime, want instant access to information—about products, orders, bills—through a variety of access points, be they phone, email, or Internet portals. All this adds up to an urgent need for some very fresh thinking about the problems and challenges of managing technology.

Executive Education: A Competitive Advantage

For many IT executives, executive education lies at the heart of successful change, and embarking on a learning course can give their careers a necessary boost. Executive education counts as a definite advantage. Thus it's small wonder that executive education programs have become so popular. According to *BusinessWeek*'s 2003 special report on executive education, businesses are turning to executive education programs once again, as reported company investments in these programs make up one-third of their funding, or $662 million in 2002-2003. That includes executive MBA programs, as well as the shorter courses and custom-designed programs that executive education programs offer.

Experts say that CIOs are embracing a far different type of educational experience than in previous years. The common element: courses teaching new concepts that can invigorate and refresh corporate technology strategies. For example, one popular executive education course at Duke University's Fuqua School of Business is its Business Improvisations program, a three-day class that teaches business executives to respond to rapid change. “The ability to be able to adapt to a situation in response to changes in the business environment is a critical skill for IT people,” explains John Cady, the associate dean for executive education at Fuqua.

There are several ways to get the most out of an executive education experience. Dave Miller, the director of business development at Duke Corporate Education Inc., a company spun off from the Fuqua School to run its corporate education program, divides executive education into three levels:

Individual Education. CIOs needing to upgrade their own understanding can choose from a variety of courses geared towards individual learners. These can range from two- or three-day short courses to actual degree programs, but the emphasis is on the needs of each particular CIO.

Departmental Education. Nevin Fouts, CIO of the Fuqua School of Business, recently sent his management staff through Innovative Leadership, a week-long program offered by Duke. Sending his entire staff will help his group function better as a whole, he says, and going off-site as a group is also a big help. "Getting away from the operational day-to-day challenges allows managers to gain new perspective," he points out.

Organizational Education. This goes beyond the CIO to embrace the entire organization, says Duke Corporate Education's Miller. Many companies are commissioning custom groups such as Miller's to build executive education courses that work on a cross-functional level. "We'll build a program that's wrapped around the actual business issues of the company," he says. "It helps a company look at the big picture and think about how to integrate information technology with marketing and finance, for example."

What's Hot

No matter how CIOs choose to do the learning, there are a number of topics cited by education experts as

Making a Choice

There is a wide range of executive education programs available to those seeking to boost their career profiles. Each has its advantages, and a quick rundown can help narrow the decision-making process.

▸ **One-topic certificate programs.** These range in length from one week for a course such as Wharton's Finance for Non-Financial Executives to Harvard's eight-week Advanced Management Program. They generally explore one particular topic, and by definition require less of a time investment than a full-blown executive MBA.

▸ **Custom-designed programs.** Many of the top schools will work with a corporation to custom-build executive education programs tailored to fit the needs of that company. Custom programs have become increasingly popular, according to *BusinessWeek*; the magazine says that the top 20 schools earned an estimated 43 percent of revenues through custom work, with programs costing anywhere from $6,000 to almost $6 million. Robert Mittelstaedt, director of executive education at the Wharton School, says that custom programs are the growth engine at Wharton, accounting for 65 percent of executive education revenue.

▸ **Executive MBAs.** The classic MBA, offered on a part-time basis for mid-career executives. Programs generally range in length from one to two years. For example, MIT, in conjunction with its Sloan School of Management, offers a one-year management of technology course that helps technology-oriented executives learn broader management skills.

popular with the IT set this year. In particular, the following ideas have proved relevant for CIOs:

Leadership. Fouts is not alone in his desire for an IT staff that is comfortable with leadership skills. As IT departments are called upon to build technical strategies that exploit corporate strengths and leapfrog the competition to competitive advantage, they need the leadership skills necessary to champion a project and gain buy-in from a wide variety of corporate sponsors.

"The leadership element is key," says Harvard Business School's Breckling, because while the CIO and his or her staff are in charge of implementing IT projects across a corporation, they aren't the ultimate users. Being able to work closely with managers from other departments and get everybody on board as users is critical to the success of any IT project, and that calls for the kinds of leadership skills taught at the advanced management programs run by top universities.

Strategy. In order for a CIO to put together an IT program that matches business targets, he or she has to be able to understand the company at a strategic business level, says Miller. "There was a time when people thought of CIOs as interchangeable, and that they could switch industries pretty easily," he says. "That's no longer true." These days, CIOs need to understand in great detail the

various elements that drive a company's profit picture. Which division is making money? Which group is not? What's the general business climate in a given market, and how will it affect a particular industry? These are the things that CIOs need to know. "They need a deep understanding of what really drives the financials of a company," says Robert Mittelstaedt, vice dean of executive education at Wharton School at the University of Pennsylvania.

To get that understanding, technical managers are turning to programs on strategy, such as the Management of Technology Program offered by MIT's Sloan School, or the Sloan Fellows program. Both offer one-year programs that intertwine general management skills and technical issues, explains deputy dean Lessard. Bottom line? "You have to be able to play in both spheres," he says. "If they're going to be successful in corporate management, CIOs need the ability to work successfully in the strategy domain."

Finance. The reality facing CIOs today is that while the value of IT has surged in the past 10 years, budgets have shrunk in response to straitened economic times. The result: CIOs are having more conversations with CFOs, who want convincing, quantifiable reasons to fund projects. According to the Wharton School's McCartney, smart CIOs will institute an ongoing conversation with their CFOs, with frequent check-ins to make sure that IT spending matches business priorities. But to do so, he notes, "You have to be able to speak the CFO's language."

Small wonder that finance remains a popular executive education course, says Mittelstaedt. "We see a lot of technical people in our Finance and Accounting for the Non-Financial Manager course," he notes.

Sales. While most CIOs know a lot about their businesses from an operational perspective, the new reality of managing IT requires them to think in entrepreneurial terms. "They need to be thinking, 'Where are our opportunities to make money?'" McCartney says. "You want the CIO to begin to think of his group as a profit center." To do so, however, he or she needs to be able to pinpoint good money-making ideas and sell them to senior management. That's why CIO representation is up at such courses as Wharton's program on building and creating businesses within larger corporations. "It helps the CIO think about the fact that he has a profit and loss statement, not just a loss statement," explains Mittelstaedt.

In the end, of course, success boils down to a CIO's ability to grow and change with the business world in which he or she functions. As the old proverb puts it, "May you live in interesting times." There's no doubt that we do, and smart CIOs will embrace the opportunity to craft a new, more strategic position from the chaos of today's world. As McCartney points out, most CIOs are fully aware that their jobs are changing rapidly, and realize that they need to seize the day. "They've just got to learn and think about the questions confronting them," he says. "Otherwise they'll have to perform the corporate equivalent of flying an airplane with no training."

Executive Education Directory

Princeton University
Undergraduate Certificate for Finance
Bendheim Center for Finance
Dial Lodge, 26 Prospect Avenue
Princeton University
Princeton NJ 08540-5296
Telephone: (609) 258-0770
http://www.princeton.edu/~bcf/

Massachusetts Institute of Technology
MIT Professional Education Programs
77 Massachusetts Avenue, 9-430
Cambridge MA 02139
Email: professional@mit.edu
http://web.mit.edu/mitpep/

Columbia University
Columbia Business School
Executive Education
Armstrong Hall, 4th Floor
2880 Broadway
New York NY 10025
Telephone: (800) 692-3932
(outside the U.S: (212) 854-3395)
http://wwwo.gsb.columbia.edu/execed/

Visit www.technologyreview.com/execed for more information on executive education programs.

Cooking Tumors

BY CORIE LOK

CANCER RESEARCHERS HAVE long sought a “magic bullet” that selectively targets tumor cells for destruction. In an attempt to enlist nanotechnology in that search, a Rice University spinoff, Nanospectra Biosciences, has developed gold-coated glass nanoparticles capable of invading a tumor and—when heated remotely—killing it.

The dimensions of the particles are the key to their effectiveness. Nanospectra’s particles measure 150 nanometers in diameter, which the company believes is the ideal size to permit passage through tumors’ characteristically leaky blood vessels. The particles should thus accumulate in tumors more than in other tissues. When near-infrared light is directed at the tumor site, either from outside the body or from a light probe inserted into the body, the particles absorb the light and heat up. As a result, the tumors get hotter than surrounding tissue and die.

In the company’s first published study, tumors in mice injected with the nanoparticles disappeared six days after the light treatment, while tumors in control-group mice grew quickly. While near-infrared light has been used as an imaging tool, “the novelty is the use of near infrared to heat tissue,” says John Frangioni, an assistant professor of medicine and radiology at Harvard Medical School who’s applying nanotechnology to cancer surgery.

In theory, the technology could be useful for the eradication of any solid tumor, such as those typical of breast, prostate, and lung cancer, says Donald Payne, Nanospectra’s president. “We think we’re a great adjunct to chemotherapy and radiation. We would be a much less toxic tool in the physician’s toolbox.”

The three-year-old company says it will seek its first round of venture capital this fall and hopes to soon begin more formal animal studies to convince the U.S. Food and Drug Administration to let it test its technology on humans. Nanospectra probably faces several more years of testing, since the application of nanotechnology to the treatment of cancer is new, not well studied, and likely to be highly scrutinized by regulatory authorities.

The first studies will focus on the safety and effectiveness of the injected particles. Most of the particles don’t go to the tumor and are instead filtered out by the liver, says Jennifer West, the company’s scientific cofounder and a bioengineering professor at Rice University. That could be a problem for the liver, says Frangioni. “The toxicity of gold remains unknown. Recent data at meetings suggest gold may be more toxic than we first believed,” he says.

Company researchers say that in early cell and animal studies, they haven’t yet seen any harmful effects from their particles. But the possible dangers of injecting people with nanoparticles are a general concern among some researchers and activist groups, who are calling for further study.

Other challenges loom. Tumor leakiness will vary from one tumor to the next, says Gregory Lanza, a professor of medicine at Washington University. The company will likely have to look into methods for more precisely targeting malignant cells, such as tagging the particles with proteins that selectively bind to cancer cells, says Oleg Salata, a nanomaterials researcher at the University of Oxford in England.

But if Nanospectra can meet these challenges, it could usher in a fundamentally new class of therapeutics and help bring nanotechnology into the doctor’s office. TR

NANOSPECTRA BIOSCIENCES

HEADQUARTERS: Houston, TX

UNIVERSITY: Rice University

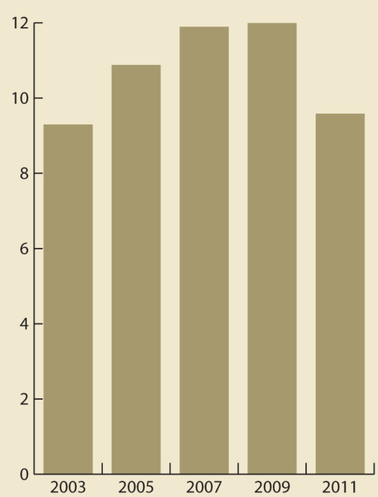
INVESTMENT RAISED: $1.1 million

LEAD INVESTORS: Private individuals

KEY FOUNDERS: Jennifer West, Naomi Halas

CANCER KILLERS

Global-market forecast for the latest generation of chemotherapy drugs ($ billion)



SOURCE: DATAMONITOR (CANCER KILLERS)

NANO FOR MEDICINE

COMPANY	TECHNOLOGY
Alnis Biosciences (Emeryville, CA)	Carbohydrate-based polymer nanoparticles that carry chemotherapeutic drugs and target cancer cells
C-Sixty (Houston, TX)	Carbon-based molecules called fullerenes, for treating neurodegenerative and cardiovascular diseases
Kereos (St. Louis, MO)	Perfluorocarbon nanoparticles for molecular imaging and targeted delivery of heart disease and cancer drugs
NanoMed Pharmaceuticals (Kalamazoo, MI)	Nanoparticles for targeted delivery of drugs to the brain to treat brain cancer, neurological diseases, and stroke

Offshore Wind Farms

ALTHOUGH WIND-ENERGY INSTALLATIONS have proliferated at an average annual rate of 28 percent over the past five years, wind power still accounts for less than 1 percent of electricity generated in the United States. Wind-energy advocates are hopeful that wind power will generate 6 percent of the nation's electricity by 2020, and their hopes have been bolstered by the development of more-efficient turbines and by government initiatives favoring renewable power. Today's turbines have larger blades, along with smart systems that analyze wind speed and direction to capture the most wind. Also, the spread of offshore wind farms in Europe has inspired some in the United States to look to harness the power of strong sea winds. A 130-turbine offshore farm in Cape Cod, the first of its kind in the nation, is set to begin construction in 2005, and the Long Island Power Authority has announced plans to build an offshore farm by 2008. Here's a look at how electricity is generated by an offshore wind farm, and how that electricity makes its way to consumers. **TEXT AND ART BY 5W INFOGRAPHIC**

How turbines generate electricity

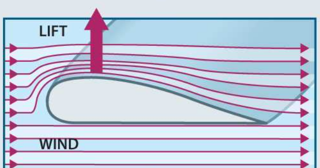
1. PRODUCING ENERGY

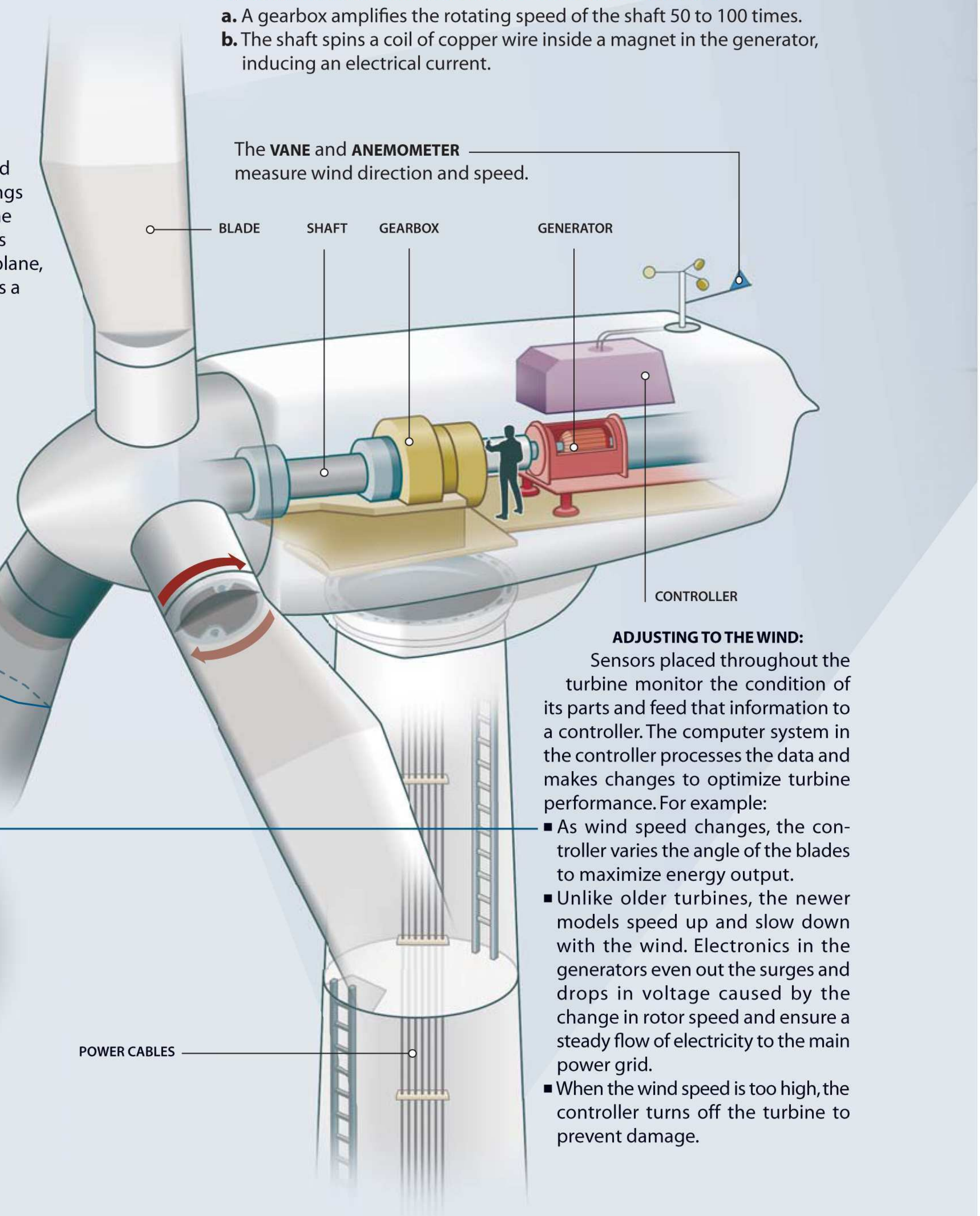
As wind moves over the blades, they rotate at about 10 to 30 revolutions per minute, causing a shaft to rotate.

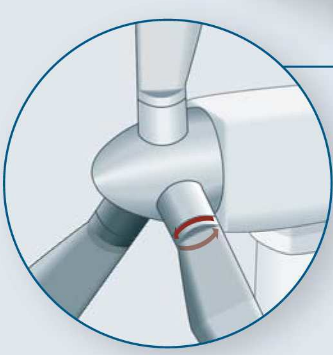
2. CONVERTING ENERGY INTO ELECTRICAL CHARGE

a. A gearbox amplifies the rotating speed of the shaft 50 to 100 times.
b. The shaft spins a coil of copper wire inside a magnet in the generator, inducing an electrical current.

AIRFOIL TECHNOLOGY: In cross section, the glass- and carbon-fiber-reinforced plastic blades are shaped like the wings of an airplane to make the most of the wind. Just as air flowing over a plane's wing generates a force that lifts the plane, air flowing over each blade generates a force that causes it to turn.



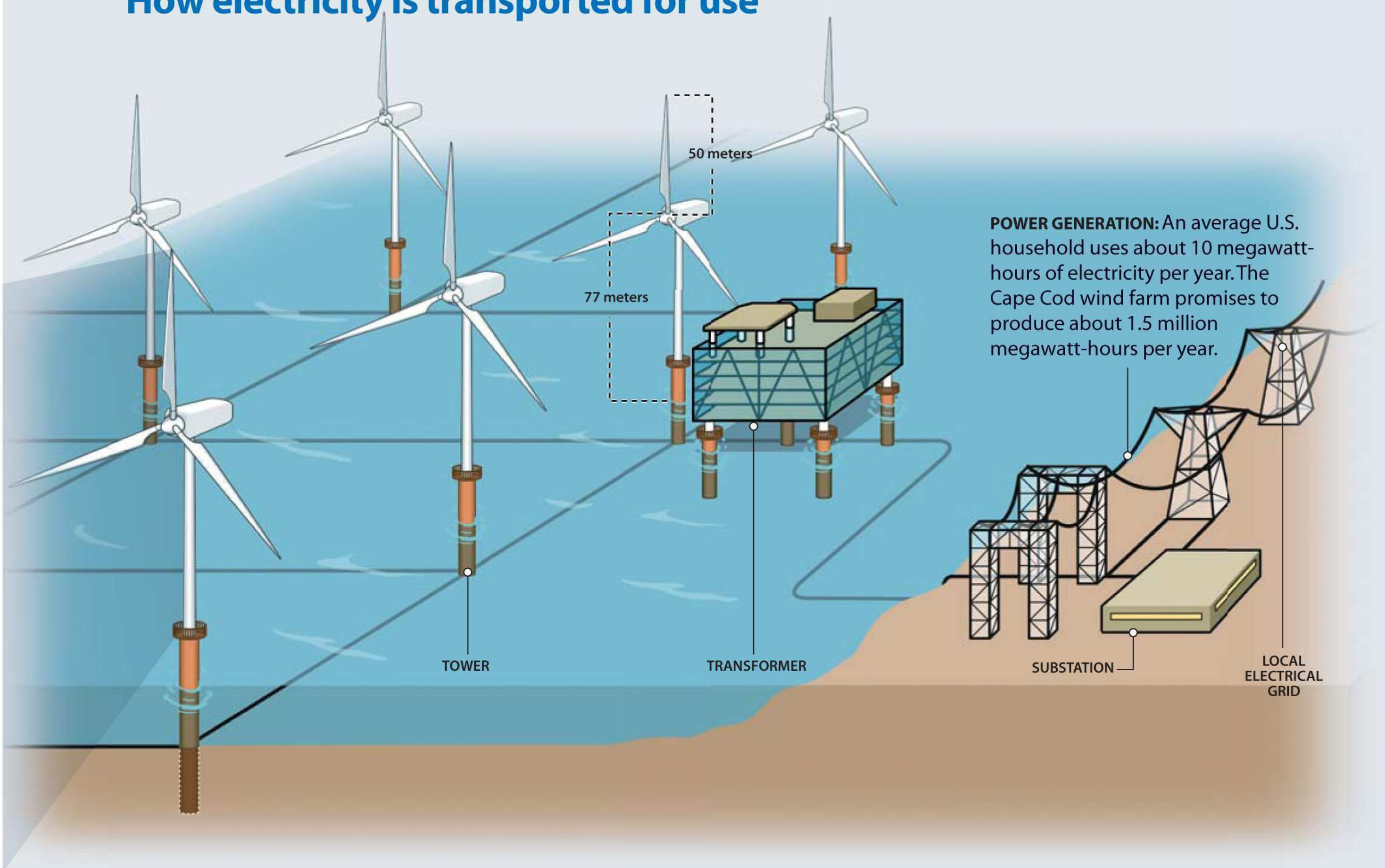




ADJUSTING TO THE WIND: Sensors placed throughout the turbine monitor the condition of its parts and feed that information to a controller. The computer system in the controller processes the data and makes changes to optimize turbine performance. For example:

- As wind speed changes, the controller varies the angle of the blades to maximize energy output.
- Unlike older turbines, the newer models speed up and slow down with the wind. Electronics in the generators even out the surges and drops in voltage caused by the change in rotor speed and ensure a steady flow of electricity to the main power grid.
- When the wind speed is too high, the controller turns off the turbine to prevent damage.

How electricity is transported for use



1. TOWER TO TRANSFORMER

Electricity from the generators runs down cables inside the hollow steel towers. Cables underneath the seafloor connect the towers in a given row to one another as well as to a transformer.

2. TRANSFORMER TO SUBSTATION

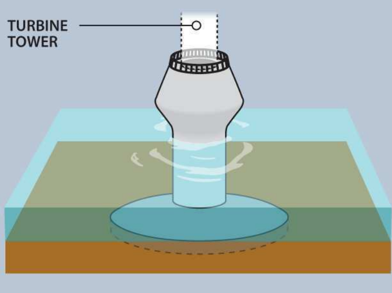
The transformer boosts the voltage before transmitting the electricity to a substation on land.

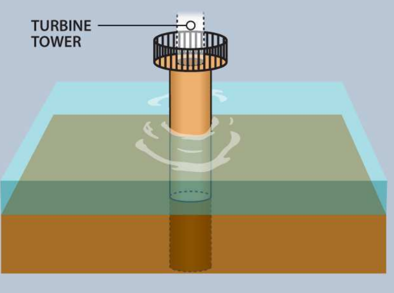
3. SUBSTATION TO LOCAL ELECTRICAL GRID

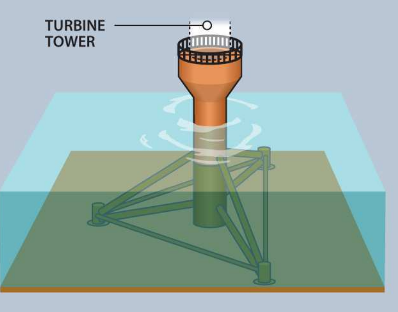
The voltage is further raised at the substation in order to make it suitable for commercial distribution. The electricity is then sent to the grid of the local electrical company.

TURBINE FOUNDATION

Methods used to secure wind turbines to the seafloor vary greatly from one farm to another, depending on soil makeup and water depth. A look at three prominent approaches:







GRAVITY BASED: Used in the very first offshore projects, these concrete foundations sit on the seabed and rely on their weight to hold the turbine upright. Ideal for rocky seafloors and shallow bodies of water.

MONOPILE: In this newer and increasingly popular method (to be used in the Cape Cod wind farm), a four- to five-meter-wide steel pile is driven some 12 to 24 meters into the seabed. Ideal for sandy seafloors and shallow bodies of water.

TRIPOD: In this method, the bottom of the turbine tower is attached to a steel frame with three legs that are driven into the seabed. Suited for bodies of water deeper than six meters.

Saved!

MY TWINS LOVE CD-ROMS BUT DON'T KNOW HOW TO take care of them. They destroyed their prized copies of Dr. Seuss's ABCs and Arthur's Birthday, two discs that Broderbund's wizards made back in the 1990s. I tried polishing the CDs and largely failed. So I threw them away and burned myself new ones. ▪ Copying CDs is an activity that most people associate with illegal music distribution and downloading. But there's nothing wrong, morally or even legally, with making backup copies of my own CD-ROMs for my own use—provided that I don't start sharing those backups with all of my friends.

The easiest way to back up a CD or CD-ROM is to copy its contents onto a recordable CD (CD-R). The danger with this approach is that CD-Rs are more fragile than commercial CD-ROMs: many have thinner-than-paper labels that are easily damaged, especially by little hands. Moreover, most CD-Rs are not archival, meaning that they can lose data as they age and deteriorate. But the biggest danger with archiving a CD on a CD-R is that it is simply too tempting to use the backup when the original dies—rather than making a copy of the copy.

Instead, I prefer to "rip" the CD-ROM, making a byte-for-byte copy of the entire disc on a 200-gigabyte hard drive that I keep specifically for this purpose. There are several disk-imaging tools available to do the copying; on my Mac, I use Apple's own Disk Utility, while on Windows, I use WinImage 6.1. These programs create a single file that's several hundred megabytes long. When the CD-ROM is inevitably damaged, I burn the image onto a fresh CD-R.

Computer hard drives die as well, of course. In the old days the standard way to back up a disk drive was onto magnetic tape. These days if you're storing less than a few terabytes, it's cheaper per gigabyte to buy external hard drives with USB or Firewire interfaces than to buy high-capacity magnetic tapes and drives. Although tape should be cheaper, disk drives have economies of scale in their favor. So I actually have two 200-gigabyte hard drives; each backs up the other.

Hard drives have become so reliable that people have stopped making backups. Alas, living without backups is living dangerously.

Children's CDs are just a few of the CD-ROM images that I have sitting on these drives. I also image practically every piece of commercial software that I buy, as well as those "installers" that I download when I purchase software over the Internet. That way I can uninstall and reinstall the software if something goes wrong—or when I buy a new computer system. (It's also important to save the corresponding activation codes.)

One of the problems that I've noticed with children's old CD-ROMs is that many of them won't run under Windows XP, Mac OS 10.3, or other modern operating systems. So in addition to archiving the CD-ROMs themselves, I've also taken to archiving all of my old Microsoft and Apple operating systems. When the hard drive on the kids' computer died last year, I reinstalled a copy of Windows 98, and they were up and running by the end of the weekend.

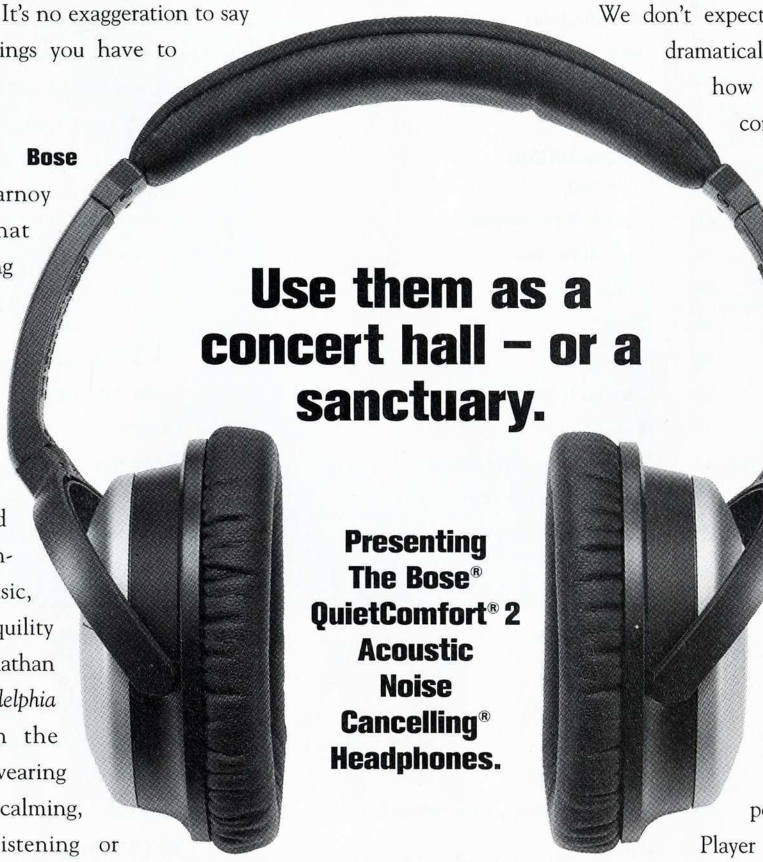
Backups are a problem for information stored not just on CD-ROMs but also on computer hard drives. Back in the bad old days of computing—say, ten years ago—most small-business users and many home computer owners religiously made backups of their data. But in recent years, hard drives have become so reliable that many people have simply stopped making backups. Alas, living without backups is living dangerously, as there are many potential ways to lose your data: fire, flood, thieves, software crashes, errant spyware—and, of course, the biggest threat of all: human error.

Now that we are all living in the 21st century, backing up computers is a chore that no one should be forced to remember. I've taken care of this by programming all of my computers to back themselves up automatically. A script that runs every night copies the contents of my documents directory to a different Zip file on that same oversized external hard drive. This backup proved to be invaluable this past summer, when my computer crashed while I was running Quicken, and the program's database was corrupted. And my Zip archives, in turn, are automatically copied from my home computer to a computer sitting under my desk at MIT—just in case my home and its contents are suddenly wiped out.

A few years ago I designed a peer-to-peer backup system based on this concept. The idea was to let businesses back up their servers, desktops, and laptops onto the spare disk space scattered throughout their offices. The network would automatically keep track of what had been backed up and where—and, of course, everything backed up would be encrypted to prevent accidental data compromises. Home users could arrange for backups between their desktops and laptops or, even better, could back up their systems to those of their friends next door.

Unfortunately, I couldn't find anybody to fund my idea. Nevertheless, many similar systems are now under development. Within a few years, it's likely that we'll all be using disk images and peer-to-peer backups to archive our most important information—and probably everything else, as well. TR

Simson Garfinkel is an incurable gadgeteer, an entrepreneur, and the author of 12 books on information technology and its impact.



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Enjoy your music with our best headphone sound quality ever. After trying QuietComfort® 2 headphones, audio critic Wayne Thompson reports that "Bose engineers have made major improvements." The sound is so clear, you may find yourself discovering new subtleties in your music. *CNET* says "All sorts of music – classical, rock, and jazz – sounded refined and natural."

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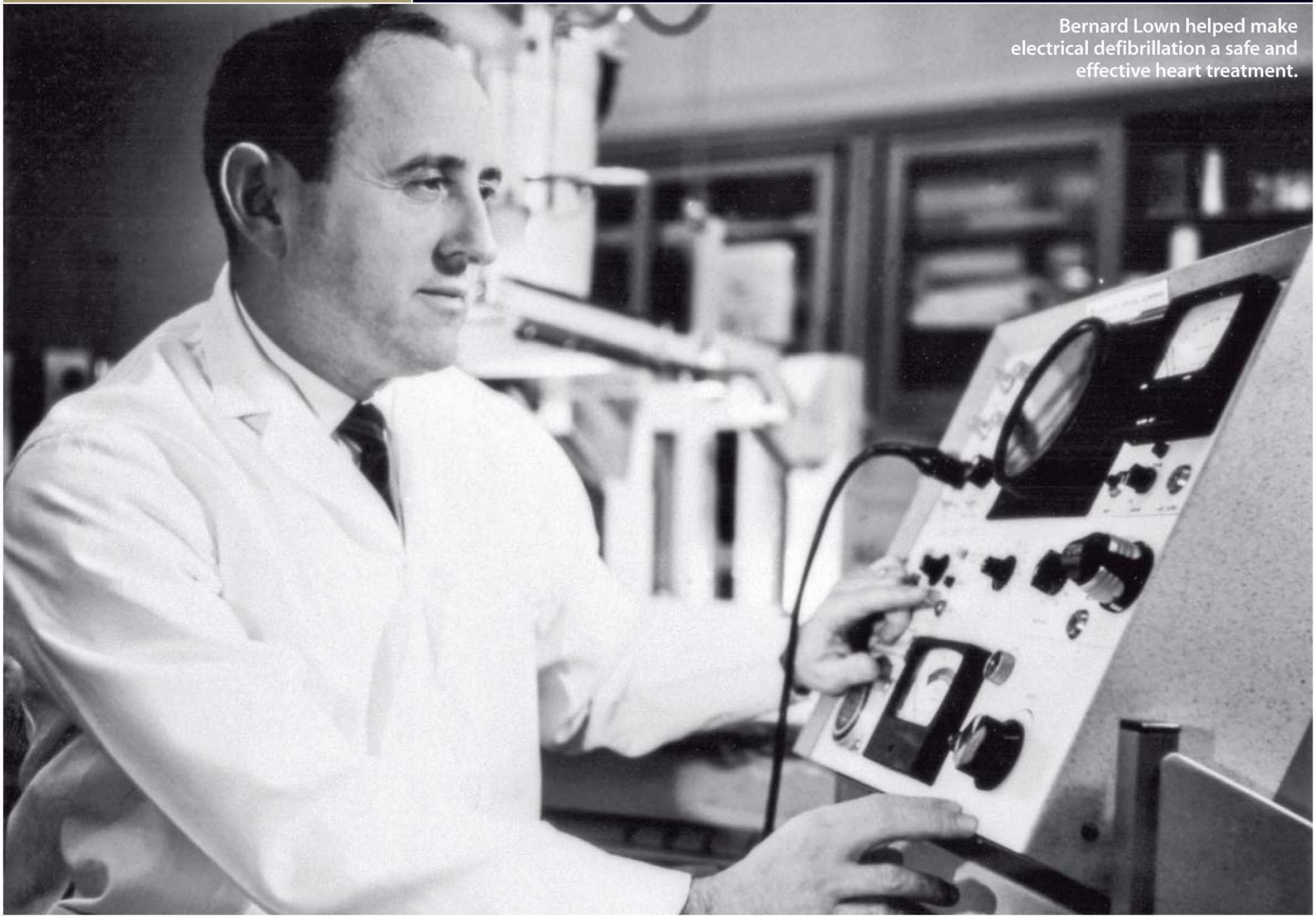

Bernard Lown helped make electrical defibrillation a safe and effective heart treatment.

Heart Restart

Bernard Lown's defibrillator saved stalled hearts. **BY DAN CHO**

THE SCENE IS FAMILIAR TO anyone who has seen a TV medical drama. The old man on the gurney goes into cardiac arrest, his heart monitor emitting an urgent whine. A doctor grabs a paddle in each hand, barks a warning—*Clear!*—and applies a jolt of electricity to the patient's bare chest. The body thrashes violently, but a tense moment later, the monitor resumes its steady beeping.

That this procedure is instantly recognizable to people who've never set foot in an emergency room is largely due to Boston physician Bernard Lown, inventor of the modern defibrillator. It wasn't always clear that passing current through a patient's body could restore a wayward heart. In 1775, a Danish veterinarian used electricity to stun and revive a chicken. It wasn't until 1955, though, that physician Paul Zoll resuscitated a human patient by applying a burst of alternating current to his chest. AC defibrillation didn't have a high success rate, but since its recipients were nearly dead anyway, its drawbacks did not receive much scrutiny.

That began to change in 1959, when 37-year-old Lown faced a desperate situation. A patient arrived at the emergency room with short breath and a rapid pulse. When the customary drugs failed to slow the man's racing heart, Lown recalled Zoll's work. Although defibrillation had never been attempted in this type of case, Lown obtained permission from the man's wife and delivered a shock to his chest. To Lown's relief, the treatment worked. But three weeks later, when the man returned with the same problem, Lown's attempt to shock the heart back to normal made the muscle contract erratically instead. Doctors opened the man's chest to apply electrodes directly to the heart. The patient survived the night but died soon after.

Lown spent a year trying to find out what had gone wrong. He finally realized that the alternating current doctors were using did enormous damage to the heart muscle. Lown enlisted engineer Baruch Berkowitz to help find a safer, more effective treatment. The two developed a defibrillator based on direct current, which delivers a single pulse of electricity instead of a current that repeatedly switches direction. Within a few years, this new machine had replaced its AC predecessor in hospitals, and it has been saving lives—on TV and in real life—since. TR

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